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MODELING AND SIMULATION
OF A SEARCH RADAR RECEIVER

by

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MODELING AND SIMULATION OF A SEARCH RADAR RECEIVER

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ABSTRACT

Evaluation of radar performance using an actual radar is extremely costly. Such a process usually provides only samples of data under limited and difficult-to-control scenarios. In contrast, computer simulation using a validated model of the radar system provides flexible and cost-effective means of testing various aspects of the system. This research represents an initial attempt on this goal: construct function-by-function validated models of radar systems for performance assessment on the computer and produce simulation software which can accept environment data and threat scenarios and drive the radar models. Several desirable aspects of radar operations have not been included in this work. Among them the multiple PRF capability and range-Doppler ambiguity resolution; ECCM features such as carrier frequency agility and sidelobe cancellation; clutter map for enhanced zero velocity target detection are the ones to be considered for implementation in the immediate future.

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I. INTRODUCTION

A. THESIS RESEARCH OBJECTIVE

Evaluation of radar performance using an actual radar is extremely costly. Such a process usually provides only samples of data under limited and difficult-to-control scenarios. In contrast, computer simulation using a validated model of the radar system provides flexible and cost-effective means of testing various aspects of the system. This research represents an initial attempt on this goal: construct function-by function validated models of radar systems for performance assessment on the computer and produce simulation software which can accept environment data and threat scenarios and drive the radar models. The radar models should be designed to accept digitized I- and Q-channel A/D converter outputs of a real radar so that the output of each functional unit can be validated against a physical unit. ?

A 60 MHz pentium processor based PC with 32 MB of RAM and 33 MHz PCI bus is utilized as the platform for this research. MATLAB with SIMULINK, written by the Mathworks, Inc. and adopted at NPS by the ECE department as standard educational software packages are used in order to take advantage of the friendly graphical user interface (GUI) of the SIMULINK environment. It is possible to generate digitized complex envelope of the intermediate frequency (IF) filter output of received signals at 1 microsecond intervals as is done in this work. But the extensive computation required of follow-on simulation cannot be completed in real time with this setup. Several immediate improvement can be made: the recently released MATLAB and SIMULINK compilers and the appearance of more powerful PC's will help improve processing speed in both the software and the hardware fronts and make real-time simulation closer to reality. Since MATLAB and SIMULINK are also available under UNIX, moving the simulation to a powerful workstation is always a possibility, even if the software is developed using a PC.

In this thesis, the software model of a generic search radar operating at a medium pulse repetition frequency (PRF) with Doppler filtering capability is created. A simulation program is written which takes this radar model, combines it with user defined trajectories and cross sections of targets and jammers to produce echo signals and displays the radar output on a plane-position indicator (PPI) and separately on a range-Doppler plane.

Beyond performance evaluation of radar systems under various threat scenarios, the validated radar models as conceived will be great research and development tools. For better utilization of existing radar systems, simulation of data fusion among several networked radar sets can be built on top of this setup. For radar improvements, every function of a validated radar system can be individually modified and tested under simulation before its implementation into a prototype.

B. SOFTWARE STRUCTURE

The software is comprised of four principal functions, as illustrated in Fig. 1.1. These are: model of the search radar itself, the definition of the scenario, the simulation of the radar echo and the simulation of the radar processing.

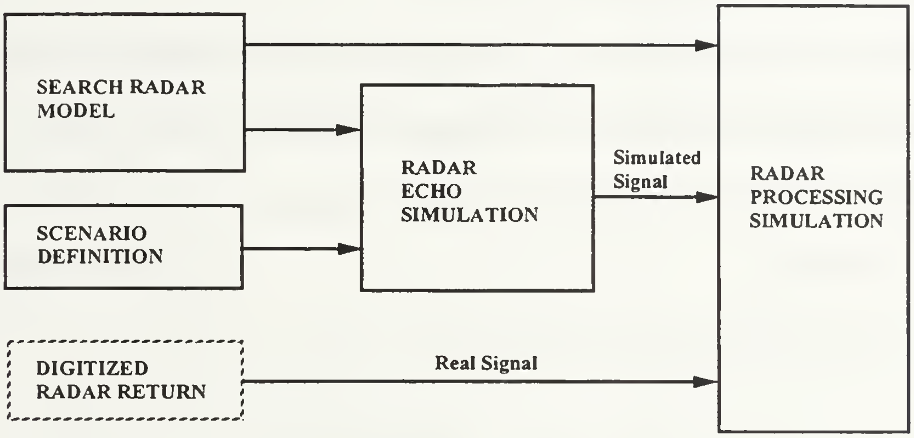


Figure 1.1 Software Structure

The search radar model is a function-by-function modeling of the radar receiver. Under simulation, the sequence of module executions follows the typical radar processing sequence. Any radar system can be modeled with a set of functional modules with defined system parameters and data handling procedure; each module can be further sub-divided into smaller modules, allowing the system to be modeled in progressively more detail.

To evaluate radar performance under a simulated environment, the ability to create a time-varying dynamic scenario containing the target trajectories, radar cross sections and jammer characteristics is made available to the user.

The simulated target returns and jamming signals are generated as radar echoes at the PRF, in accordance with the specified scenario and antenna pattern. The non-moving radar echoes are added at the video frequency at the sampling rate to the I (in-phase) and Q (quadrature) channels. Since the currently constructed model is just an example, mainly for testing the simulation software and not the model of a particular radar system, the capability of accepting digitized I and Q output signals from a real radar system is not considered, although its implementation is trivial.

During a simulation, the signal processing output of each subfunction module can be monitored and analyzed. A simulated PPI display of the status of the radar is continuously updated and the amplitude and phase of the processed signals can be extracted and displayed.

The structure of the software is shown in Fig. 1.2.

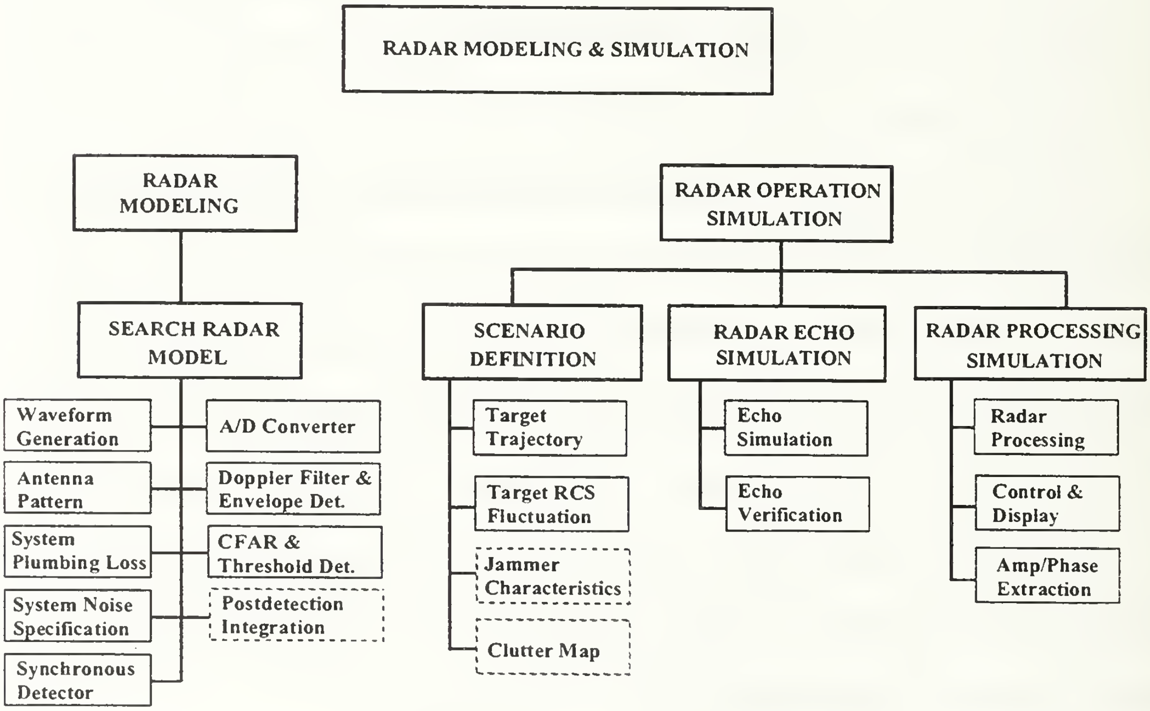


Figure 1.2 Software Structure Break-down

II. RADAR MODELING

A. SEARCH RADAR MODEL

The functional diagram of a typical air search radar receiver used is illustrated in Fig. 2.1.

1. Waveform Generation

The radar waveform is specified by system parameters as the following and illustrated in Fig. 2.2.

System parameters:

- f = RF (900 MHz)
- f_o = IF frequency (30 MHz)
- P_t = peak transmit power (280 kW)
- either f_r = PRF (1 kHz) or $T = \frac{1}{f_r}$ = PRI (1000 μs)
- τ = PW (2 μs) = range bin width
- T_R = receiver recovery time (8 μs)
- t_a = sampling time (2 μs), a submultiple of τ

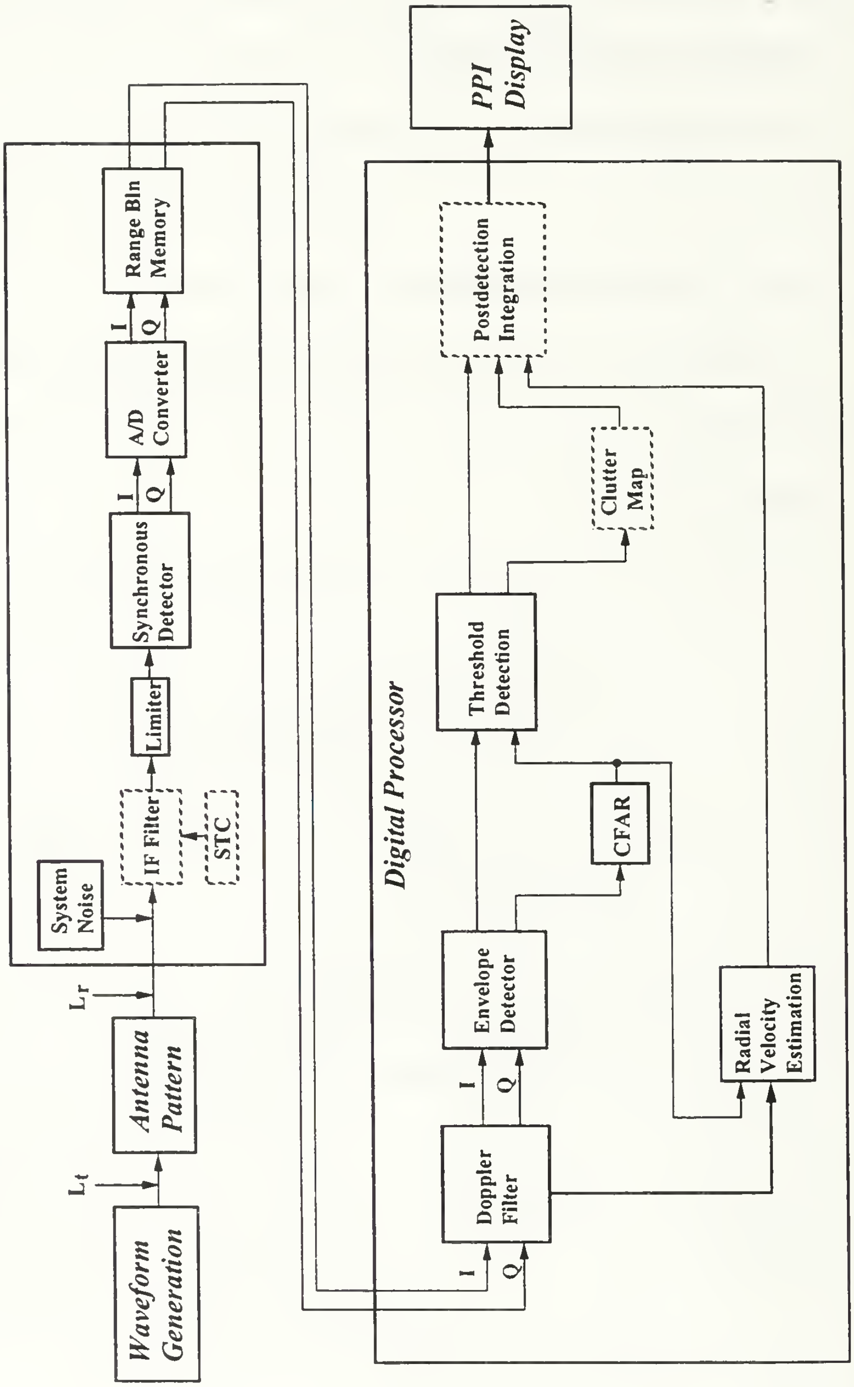


Figure 2.1 Functional Diagram of Search Radar Model

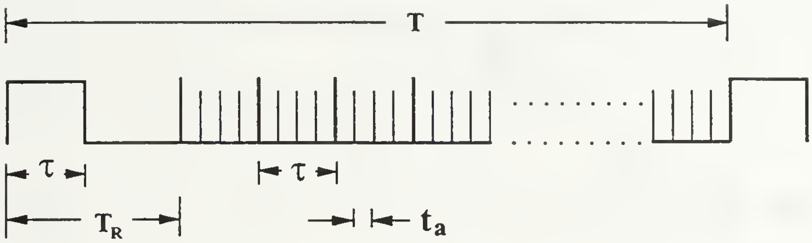


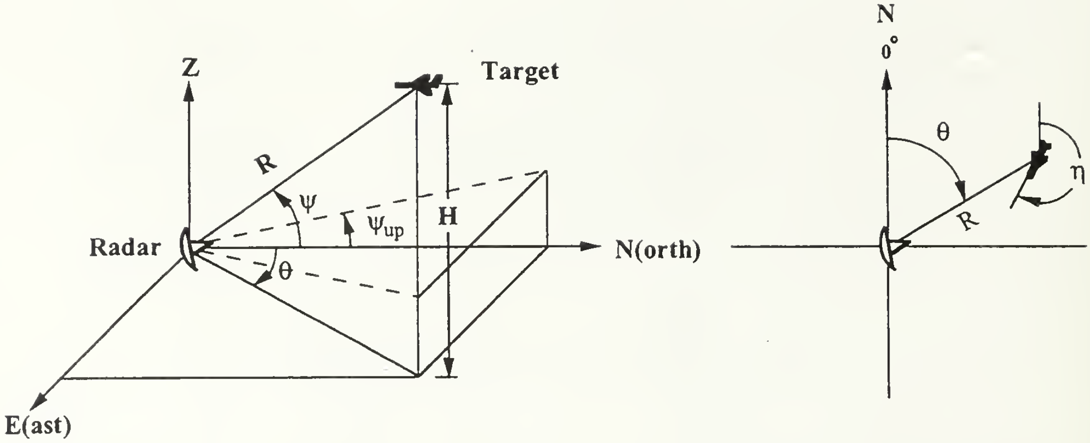
Figure 2.2 Definition of Radar Waveform

The sampling interval should be equal to the pulse width or its submultiple so that the radar echo from each range bin can be accurately represented.

With a single medium PRF, both the estimated range and the Doppler velocity of a detected target may be ambiguous. A commonly used technique to resolve these ambiguities is to employ multiple PRF's. Such a technique has been widely adopted in current radar systems and should be included in such models.

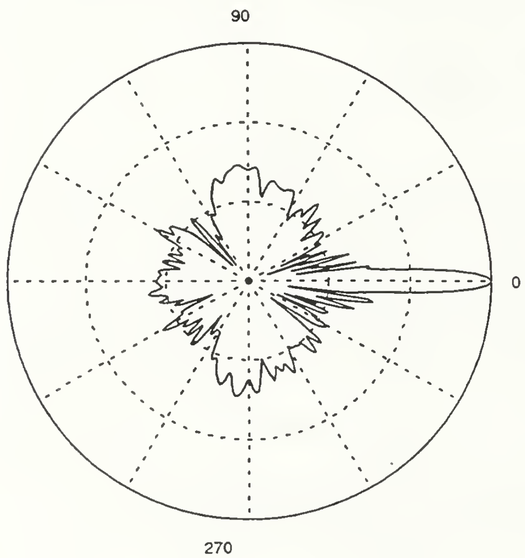
2. Antenna Radiation Pattern

The strength of returned signals from a target change steadily in a radar which scans mechanically in azimuth. The target is in different azimuth and elevation of the mainbeam for successive pulses, therefore, as the beam traverses the target, the received train of pulses are amplitude modulated with the two-way gain of the antenna, as shown in Fig. 2.3. To give an accurate description of the radar echoes and the jamming noise, a digitized 3-D reflector antenna pattern based on that of an AN/SPS-49 radar [Ref. 1], including all sidelobes for ECCM applications, is specified.

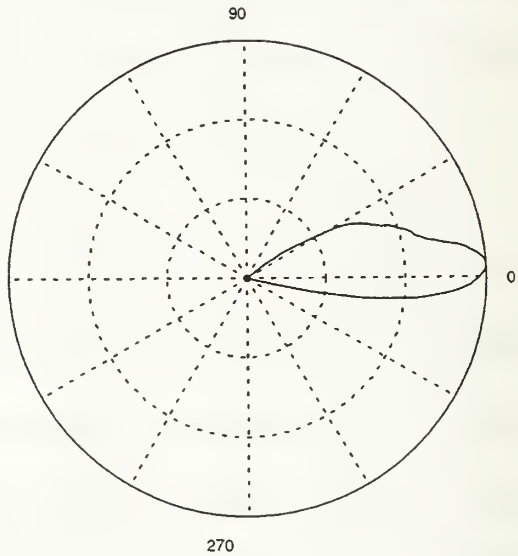


H : target altitude R : target slant range
θ : bearing η : target heading
ψ: elevation ψ_{up} : upspot angle

(a) Target coordinates



(b) Azimuth antenna pattern



(c) Elevation antenna pattern

Figure 2.3 Target Position Relative to Antenna Gain

System parameters:

- $G_t = G_r = G =$ antenna mainbeam peak gain (28.5 dB)
- ψ_{up} = air search upspot angle (12 degree)
- f_s = scan rate (12 RPM)
- θ_{3dB} = half-power beam width (3.3 degree)

Modeling procedure:

step 1: Digitize the real antenna patterns (Fig. 2.4) by 1° resolution.

Obtain gain attenuation in dB.

$G_{AZ}(\theta)$, $-180^\circ \le \theta < 180^\circ$ (resolution 1°)

$G_{EL}(\psi)$, $-20^\circ \le \psi < 40^\circ$ (resolution 1°, specified to -30 dB only, neglect the rest)

where $$\psi = \sin^{-1}(\tfrac{H}{R}) - \psi_{up} \quad (2.1)$$

step 2: Interpolate θ resolution from 1° to pulse-increment angle $\Delta\theta$.

Obtain synthesized 3-D antenna pattern.

$G_{AZ}(\theta)$, $-180^\circ \le \theta < 180^\circ$ (resolution $\Delta\theta$)

where $$\Delta\theta = \tfrac{f_s}{f_r} \times 360^\circ \quad (2.2)$$

step 3: Establish azimuth and elevation antenna gain look-up tables.

$$G(\theta, \psi) = G + G_{AZ}(\theta) + G_{EL}(\psi) \quad \text{(dB)} \quad (2.3)$$

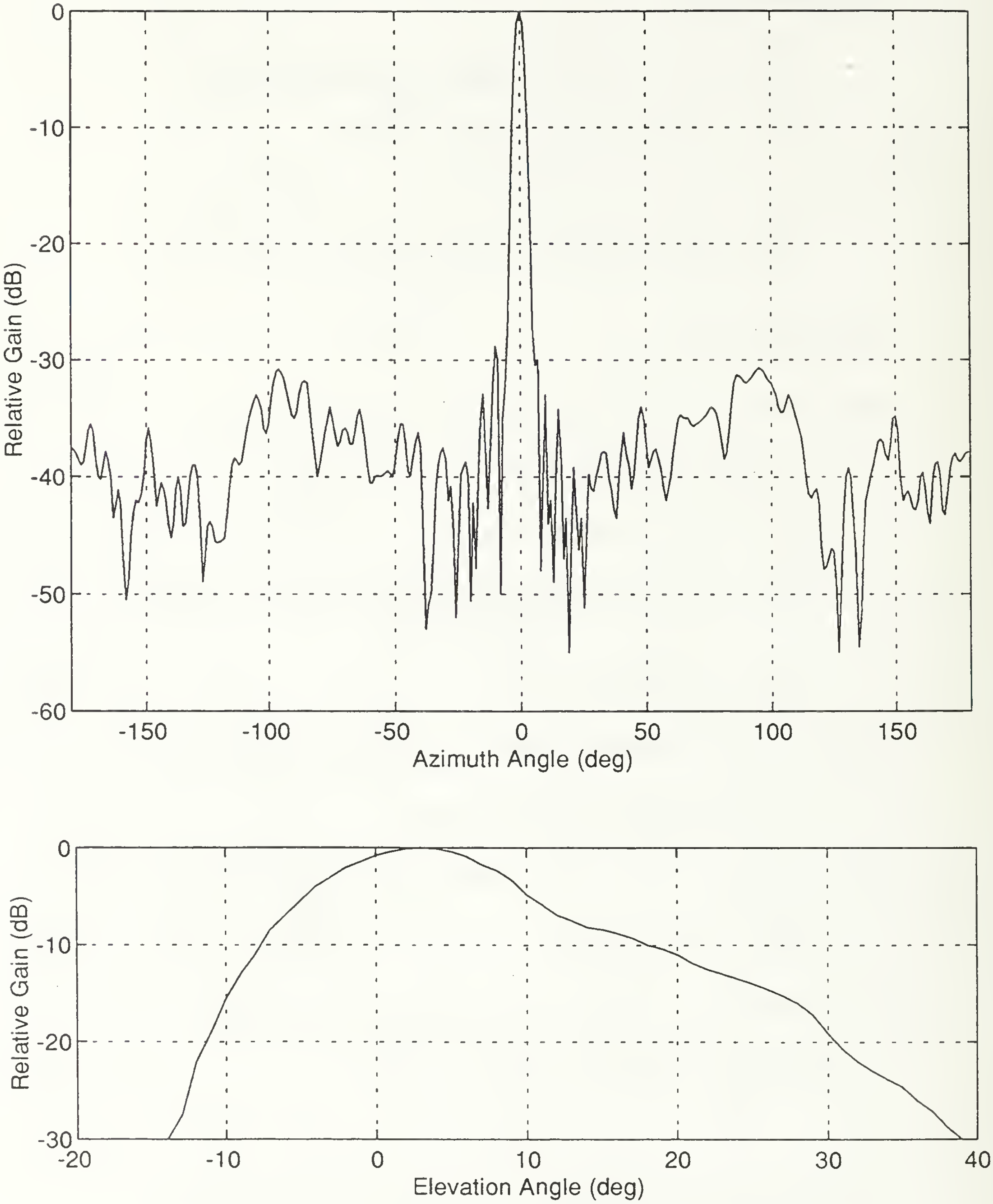


Figure 2.4 Digitized Reflector Antenna Pattern

3. System Plumbing Loss and System Noise Specification

The loss of power within the radar system itself comes from many sources. Since the processing loss at every stage is simulated, only system plumbing loss needs to be specified separately in the following:

System parameters:

- L_s = system plumbing loss (2 dB)
- L_t = plumbing loss (dB), transmitting
- L_r = plumbing loss (dB), receiving

Modeling procedure:

The system plumbing loss is determined by:

$$L_s = L_t + L_r \quad \text{(dB)} \quad \text{or by defined value} \tag{2.4}$$

The ability of the radar to detect the target echo depends not only on the signal power, but also on the competing noise present in the receiver. The usual noise that exists in a radar receiver is mostly of thermal origin. They are summarized below and shown in Fig. 2.5.

System parameters:

- T_s = system noise temperature (°K)
- T_a = antenna noise temperature (°K)
- T_r = transmission-line noise temperature (°K)
- T_e = receiver noise temperature (°K)
- L_r = plumbing loss (dB), receiving

- B_n = receiver noise bandwidth (1 MHz)
- F_n = receiver noise figure (2.5)

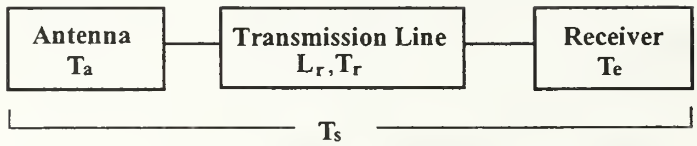
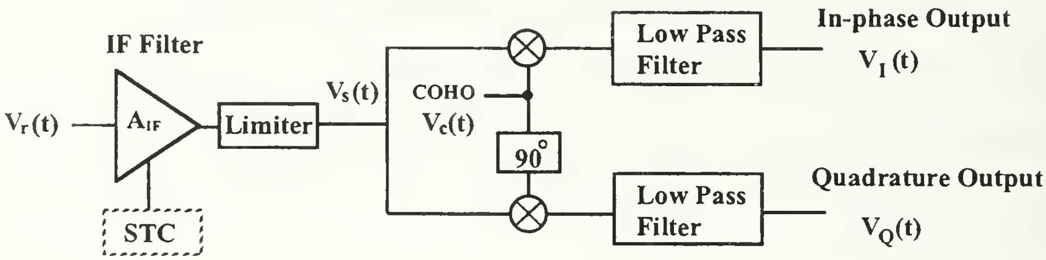


Figure 2.5 Temperature Components in a Cascade Receiving System

4. Synchronous Detector and A/D Converters

The Doppler shift in a pulsed radar manifests itself as the change in the phase of target echo signals from pulse to pulse. The process of I and Q demodulation is shown in Fig. 2.6.



$V_r(t)$ = target echo voltage into IF filter
$\omega_o = 2\pi f_o$, f_o = IF frequency
$\phi = 2\pi f_d$, f_d = target Doppler frequency
$V_s(t) = A_{IF} \cdot V_r \cdot \cos[\omega_o t + \phi(t)]$ = target echo voltage out of IF filter
$V_c(t) = 2 \cdot \cos[\omega_o t]$ = COHO voltage
$V_I(t) = V_s \cdot \cos[\phi(t)]$ = in-phase voltage
$V_Q(t) = V_s \cdot \sin[\phi(t)]$ = quadrature voltage

Figure 2.6 I and Q Demodulation Block Diagram

The two signals, I and Q completely represent an echo signal, with I being the real component and Q being the imaginary. The signal processor, given the two components, reconstructs the signal amplitude and phase.

$$V_s \cdot e^{j2\pi f_d t} = V_s \cdot \cos(2\pi f_d t) + jV_s \cdot \sin(2\pi f_d t) = V_I + jV_Q \tag{2.5}$$

$$V_s = \sqrt{V_I^2 + V_Q^2} \tag{2.6}$$

$$2\pi f_d = \tan^{-1}\left(\frac{V_Q}{V_I}\right) \tag{2.7}$$

The synchronous detector can be specified and modeled using SIMULINK according to the following steps.

<u>System parameters:</u>

- A_{IF} = IF filter gain (10)
- V_{max} = limiter maximum voltage (0.01 Volts)
- f_o = IF frequency (30 MHz)

<u>Modeling procedure:</u>

step 1: Define the amplitude, frequency and phase of $V_c(t)$.

COHO cos : amplitude = 2, freq. = $2\pi f_o$, phase = 0

COHO sin : amplitude = 2, freq. = $2\pi f_o$, phase = $\pi/2$

step 2: Define the filter type, cutoff frequency and order of the lowpass filters (LPF).

step 3: Amplify the input target echo voltage.

$$V_s(t) = A_{IF} \cdot V_r(t) \qquad \text{(Volts)} \tag{2.8}$$

step 4: The input signal is then limited by a limiter.

$$V_s(t) = \min[V_s(t), V_{max}] \tag{2.9}$$

step 5: Obtain the video output $V_I(t)$ and $V_Q(t)$.

The synchronous detector model is shown in Fig. 2.7.

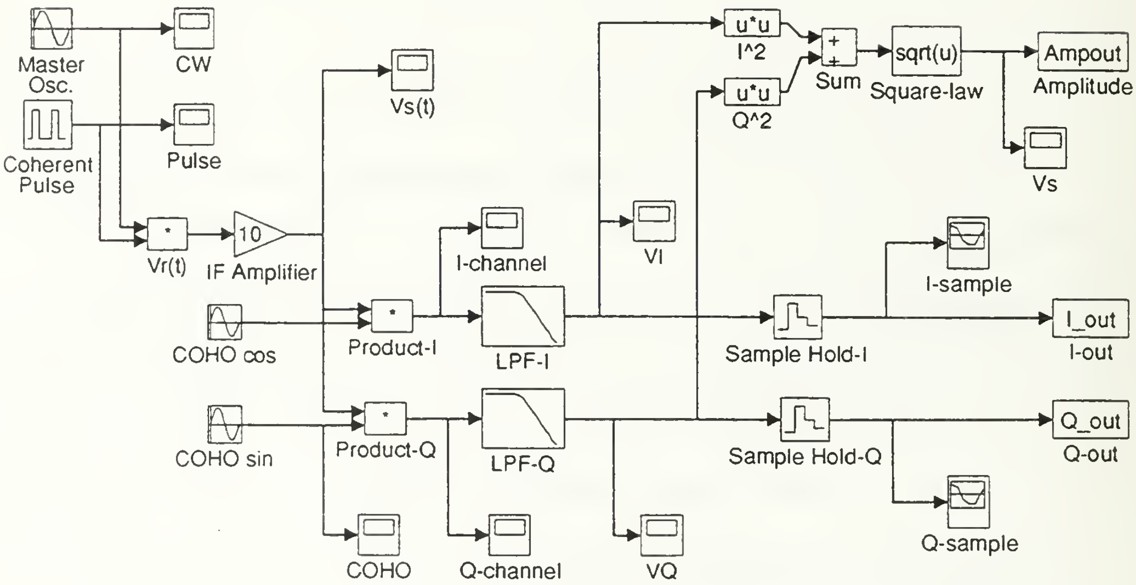


Figure 2.7 Synchronous Detector Model

The two analog-to-digital (A/D) converters provide digitized values of the I and Q voltages for the follow-on digital signal processing. To better utilize the dynamic range of the A/D converters, a sensitivity time control (STC) circuit is provided which can be turned on to adjust the gain of the IF filter. The IF filter is followed with a limiter which cuts the signal voltage off a specified level to prevent a strong echo from saturating the synchronous detector (Fig. 2.8).

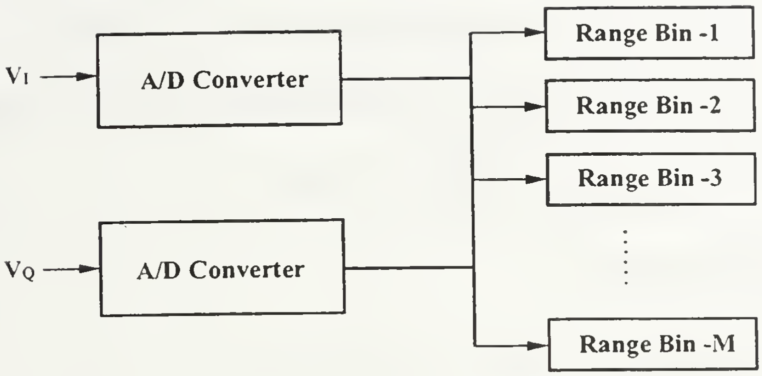


Figure 2.8 Block Diagram of A/D Converter

System parameters:

- V_{max} = limiter maximum voltage (0.01 Volts)
- V_{min} = minimum voltage (0 Volts)
- N_{AD} = number of binary digits for A/D converter (12)

Modeling procedure:

step 1: Convert binary value of input V_I and V_Q.

$$I(t) = (V_I(t) - V_{min})/dV\ ,\ Q(t) = (V_Q(t) - V_{min})/dV \tag{2.10}$$

where $$dV = (V_{max} - V_{min})/(2^{N_{AD}} - 1) \tag{2.11}$$

The range bin memory used for storing the signal I and Q can be specified and modeled according to the following steps.

System parameters:

- $R_{min} = c \cdot (\tau + T_R)/2$ = minimum detection range (0.81 nmi)

- R_u $= c \cdot T/2$ = unambiguous range (81 nmi)
- dR $= c \cdot \tau/2$ = range resolution (300 m or 0.162 nmi)
- $\Delta\theta$ $\doteq (f_s / f_r) \cdot 360^\circ$ = pulse-increment angle (0.072 degree)
- θ_{scan} = scan sector (0 to 360 degree)

Modeling procedures:

step 1: Define range bin memory array (Fig. 2.9).

RBM(1 : N, 1 : M)

where $M = (\tau / t_a) \cdot (R_u - R_{min})/dR$ for unambiguous range (2.12)

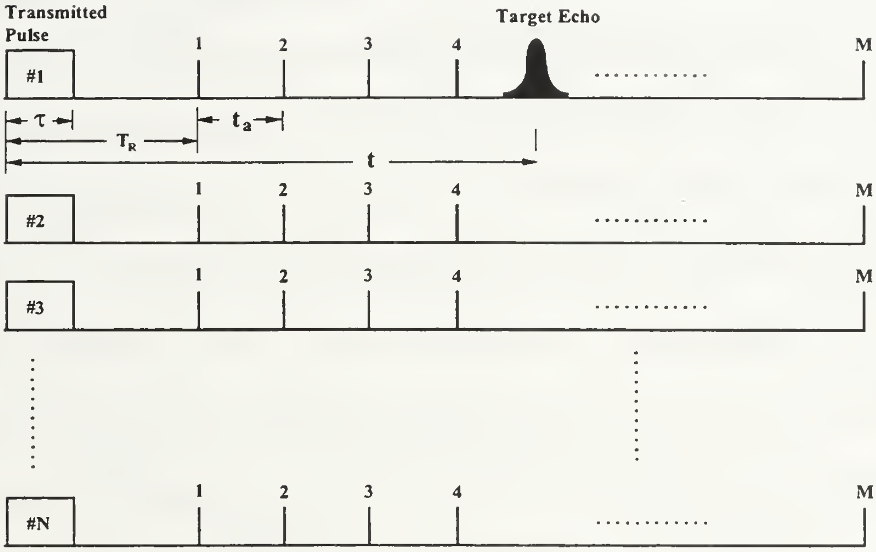
$N = \theta_{scan} / \Delta\theta$ for a scan sector (2.13)

step 2: Determine the range bin of the input signal according to time delay t and mainbeam direction θ_{MB}.

$$n = \theta_{MB} / \Delta\theta \tag{2.14}$$

$$m = (t - T_R)/ t_a \tag{2.15}$$

$$RMB(n, m) = I(t) + jQ(t) \tag{2.16}$$



Range Bin Memory

Pulse No. \ Range Bin No.	1	2	3	4	....	M
1	I,Q(1,1)	I,Q(1,2)	I,Q(1,3)	I,Q(1,4)	....	I,Q(1,M)
2	I,Q(2,1)	I,Q(2,2)	I,Q(2,3)	I,Q(2,4)	....	I,Q(2,M)
3	I,Q(3,1)	I,Q(3,2)	I,Q(3,3)	I,Q(3,4)	....	I,Q(3,M)
4	I,Q(4,1)	I,Q(4,2)	I,Q(4,3)	I,Q(4,4)	....	I,Q(4,M)
5	I,Q(5,1)	I,Q(5,2)	I,Q(5,3)	I,Q(5,4)	....	I,Q(5,M)
⋮	⋮	⋮	⋮	⋮	....	⋮
N	I,Q(N,1)	I,Q(N,2)	I,Q(N,3)	I,Q(N,4)	....	I,Q(N,M)

Figure 2.9 Organization of Range Bin Memory

5. Doppler Filter and Envelope Detector

Doppler processing allows a moving target to be detected under strong clutter. It also provides information for estimating the radial velocity of a target so that higher threat targets can be identified and future locations of targets can be predicted for track confirmations. To carry out the processing, the digitized I and Q data from pulse to pulse are applied to a bank of Doppler filters (Fig. 2.10), each of which is designed to pass a narrow band of frequencies. The filters are numbered from 1 and tuned to a progressively higher frequency corresponding to a higher target speed. To cover all Doppler frequencies up to the PRF, the center frequencies of the filters are spaced so the pass bands overlap.

For this model, the fast Fourier transform (FFT) is implemented as a generic Doppler filter. A set of pulses from one single range is processed by the filter at a time. The envelope detector provides square-law approximation of signal amplitude and detects peak amplitude of the integrated pulses.

<u>System parameters:</u>

- N_f = number of filters for a Doppler filter bank (32)
  = number of pulses integrated
- f_r = PRF (1 kHz)
  = passband of filter bank

<u>Modeling procedure:</u>

step 1: At the end of every integration period, obtain the magnitude of the response of each Doppler filter bank.

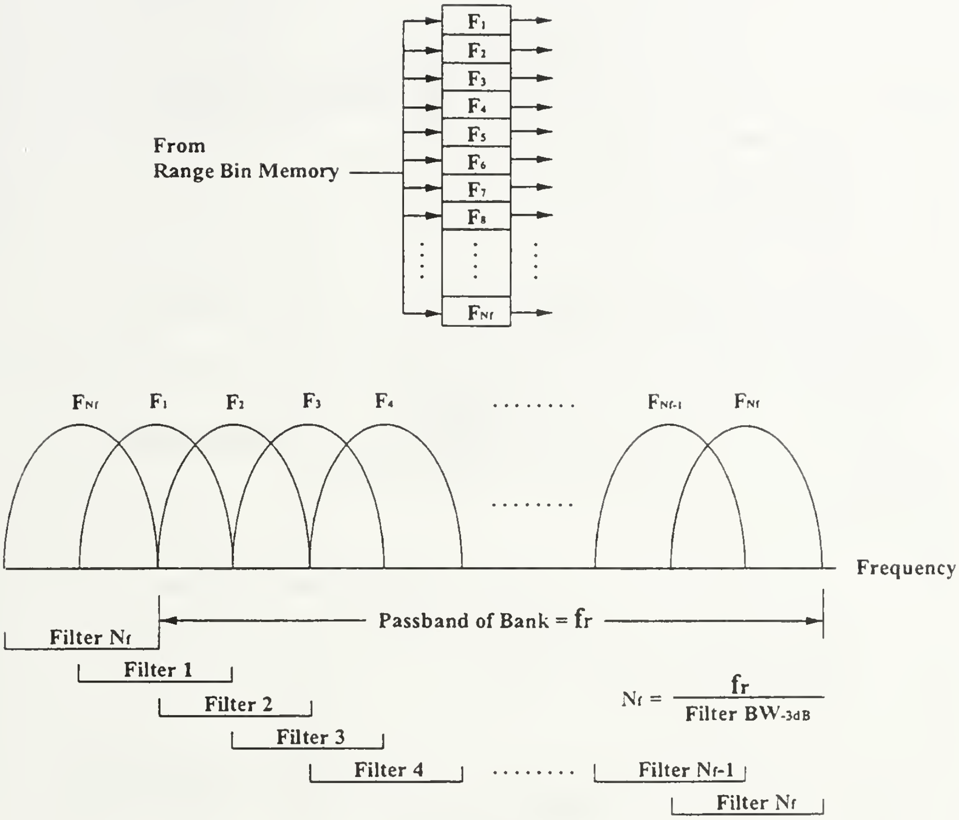


Figure 2.10 Block Diagram of Doppler Filter Bank

step 2: Estimate the Doppler frequency of a target by detecting two adjacent filters.

$$f_d = F_n - [\tan^{-1}(\tfrac{A_n}{A_{n-1}}) / (\pi/4)] \cdot \tfrac{f_r}{2N_f} \quad \text{(Hz)} \quad \text{or} \tag{2.17}$$

$$f_d = F_n + [\tan^{-1}(\tfrac{A_n}{A_{n+1}}) / (\pi/4)] \cdot \tfrac{f_r}{2N_f} \quad \text{(Hz)} \tag{2.18}$$

where $$F_n = (n-1) \cdot \tfrac{f_r}{N_f} \quad , \quad n = 1,\ N_f \tag{2.19}$$

step 3: Obtain approximate signal amplitude by using a square-law detector:

$$\text{Amp} = \sqrt{I^2 + Q^2} \tag{2.20}$$

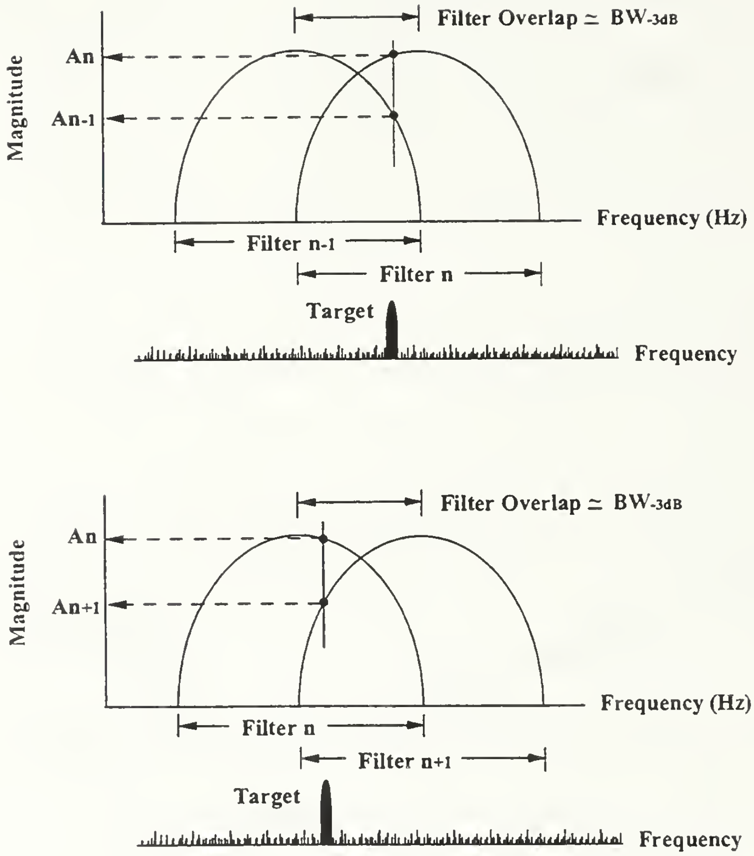


Figure 2.11 Target Response Doppler Frequency

As an example, simulated Doppler filter outputs and estimated Doppler frequencies of two targets, obtained using $f_r = 1$ kHz, $f_{d1} = 300$ Hz, $f_{d2} = 825$ Hz, $Amp_1 = 0.6$, $Amp_2 = 1.0$, are shown in Fig. 2.12. The estimated frequencies are $f_{d1} = 301.7519$ Hz, $f_{d2} = 823.8510$ Hz.

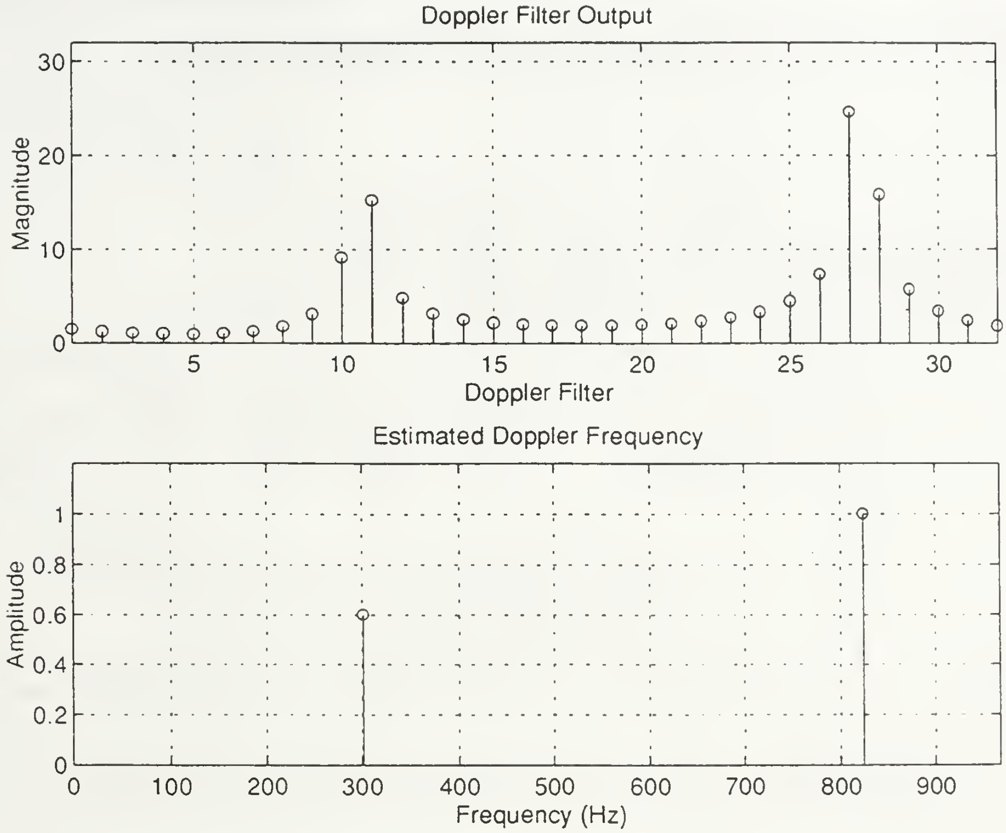


Figure 2.12 Simulated Target Response Doppler Frequency

6. CFAR and Threshold Detection

The constant false alarm rate (CFAR) processor is useful for detecting radar targets in a background where all parameters of the statistical distribution of the clutter are not known and may be nonstationary. Three common mean-level CFAR techniques called cell averaging (CA), greatest of the selection logic (GO) and smallest of the selection logic (SO) are shown in Fig. 2.13.

CA-CFAR is the optimum CFAR processor in a homogeneous background when the reference cells contain independent and identical clutter distributions. GO-CFAR presence fails to detect closely spaced targets. SO-CFAR processor attempts to resolve multiple targets near clutter edges and to prevent excessive false alarm.

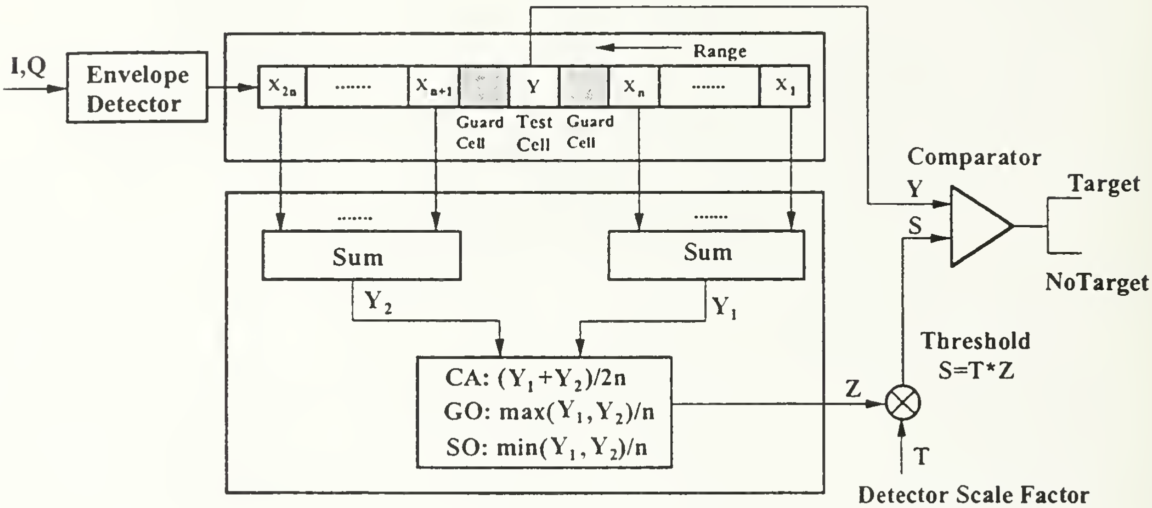


Figure 2.13 Block Diagram of the Mean-level CFAR Processor

System parameters:

- P_{fa} = probability of false alarm (10^{-4})
- 2n = detection window (16)

Modeling procedure:

step 1: The threshold multiplier T is a constant detector scale factor used to achieve a desired constant false alarm probability P_{fa} for a given sliding window of size 2n, and two guard cells will be included on either side of the range sample of interest. The numerical solution for T is summarized in Table 2.1 [Ref. 2].

- CA-CFAR:

$$P_{fa} = (1 + T_{CA})^{-2n} \tag{2.21}$$

- GO-CFAR:

$$P_{fa} = 2(1 + T_{GO})^{-n} - 2 \sum_{i=0}^{n-1} \binom{n+i-1}{i} (2 + T_{GO})^{-(n+i)} \tag{2.22}$$

- SO-CFAR:

$$P_{fa} = 2 \sum_{i=0}^{n-1} \binom{n+i-1}{i} (2 + T_{SO})^{-(n+i)} \tag{2.23}$$

Table 2.1 CFAR Constant Detector Scale Factor

	2n= 8			2n= 16			2n= 24			2n= 32		
P_{fa}	T_{CA}	T_{GO}	T_{SO}	T_{CA}	T_{GO}	T_{SO}	T_{CA}	T_{GO}	T_{SO}	T_{CA}	T_{GO}	T_{SO}
1e-4	2.162	3.6	10.88	0.778	1.36	2.444	0.468	0.833	1.277	0.334	0.602	0.851
1e-6	4.623	7.78	36	1.371	2.42	5.131	0.778	1.4	2.347	0.54	0.983	1.475
1e-8	9	15.3	117.9	2.162	3.84	9.905	1.154	2.092	3.916	0.778	1.425	2.302

step 2: Compute threshold S and detected test cell Y

- CA-CFAR:

$$S_{CA} = T_{CA} \cdot \frac{\left[\sum_{i=1}^{n} X_i + \sum_{i=n+1}^{2n} X_i\right]}{2} \tag{2.24}$$

- GO-CFAR:

$$S_{GO} = T_{GO} \cdot \frac{\max\left[\sum_{i=1}^{n} X_i , \sum_{i=n+1}^{2n} X_i\right]}{n} \tag{2.25}$$

• CA-CFAR:

$$S_{SO} = T_{SO} \cdot \frac{\min\left[\sum_{i=1}^{n} X_i,\ \sum_{i=n+1}^{2n} X_i\right]}{n} \tag{2.26}$$

If $Y > S$ the target is visible otherwise the target is invisible.

7. Postdetection Integration (PDI)

If the number of pulses for Doppler integration is less than the time-on-target, the output of each Doppler filter over the time-on-target can be integrated postdetection. The resultant integrated amplitude from a range bin and a Doppler frequency bin can be assigned a pulse number as follows: if the first Doppler filter output is from pulses 1 to N_f, and the last Doppler filter output integrated postdetection is N_{PDI} to $N_{PDI} + N_f$, then this postdetection integrated amplitude is assigned the pulse number equal to the integer part of $N_f + N_{PDI}/2$. This moving window integration scheme is shown below (Fig. 2.14) and is often called beam splitting. It is performed to improve the estimate of target bearing to within $\Delta\theta$.

<u>System parameter:</u>

- N_{pot} = number of pulses on target = $\frac{\theta_{3dB}}{6 \times f_s} \cdot f_r$
- N_f = number of pulses integrated $\leq \frac{f_r}{\text{Filter } BW_{-3dB}}$
- N_{PDI} = number of pulses integrated postdetection $\leq N_{pot} - N_f + 1$

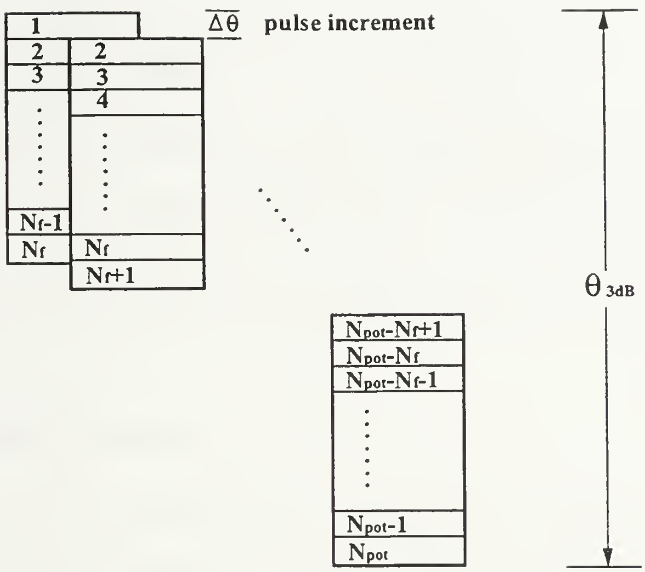


Figure 2.14 Moving Window Postdetection Integration

III. RADAR OPERATION SIMULATION

A. SCENARIO DEFINITION

There are three sources which contribute to radar return: targets, jamming signals and clutter. A time-varying dynamic scenario definition scheme consisting of the target trajectory, target radar cross section and some simple types of jammers has been implemented.

1. Target Trajectory

A realistic scenario should include the trajectories of a specified number of targets. The flight path of each target platform is made up of one or more segments of straight or turning sections of the aircraft. A complex flight path can be defined by simply linking together straight and turning segments, in addition to climbing/diving and acceleration/deceleration.

In this simulation program, only straight flight paths at constant altitudes and fixed velocities are allowed (Fig. 3.1). The coordinates (range, azimuth, altitude) and velocity (heading, speed) for each target are specified individually.

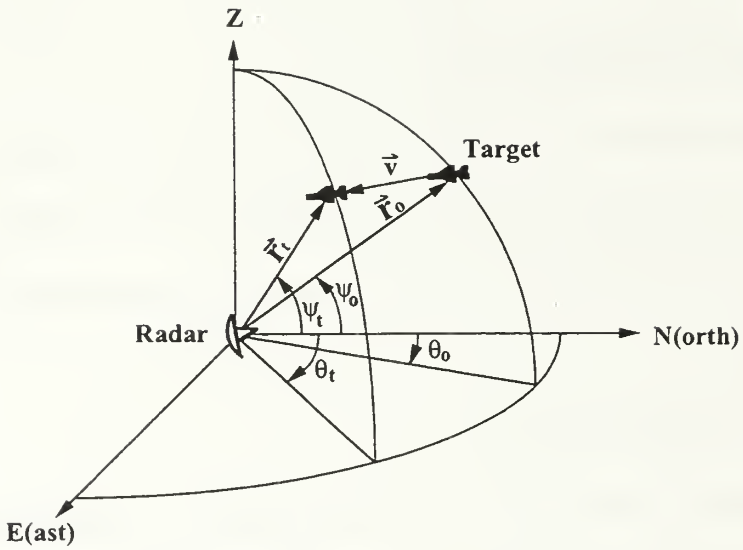


Figure 3.1 Target Trajectory

User defined parameters: (for each target)

- $\vec{r}_\circ = r_{\circ_N}\hat{N} + r_{\circ_E}\hat{E} + z_\circ\,\hat{z}$
- $\vec{v} = v_{\circ_N}\hat{N} + v_{\circ_E}\hat{E} + v_{\circ_Z}\,\hat{z}$

Simulation procedure:

Calculate the pulse-to-pulse target location.

$$\vec{r} = \vec{r}_\circ + \vec{v}\cdot t \;\;, R_t = |\vec{r}| \tag{3.1}$$

$$\theta_t = \mathrm{atan2}(r_{\circ_E} + v_{\circ_E}\cdot t,\; r_{\circ_N} + v_{\circ_N}\cdot t) \tag{3.2}$$

$$\psi_t = \sin^{-1}[(z_\circ + v_{\circ z}\cdot t)/R_t] \tag{3.3}$$

2. Target RCS Fluctuation

The most commonly used target radar cross section (RCS) fluctuation models are those investigated by Swerling. Swerling considered four cases, which differ in the assumed rate of fluctuation and the assumed statistical distribution of the RCS σ. The two assumed rates are: (1) a relatively slow fluctuation, such as the values of σ fluctuates independently from scan to scan but remain virtually constant from one pulse to the next; and (2) a relatively fast fluctuation, so that the values of σ fluctuate independently from pulse to pulse within a scan. The two assumed statistical distributions of σ are: (1) the target consists of many independent scattering elements in which no single one dominates (a Rayleigh target), its pdf is given by eq. (3.5); and (2) a target having one main dominant scattering element together with many smaller independent scatterers, its pdf is given by eq. (3.6). A non-fluctuating target with a constant σ is also often considered and is designated as Swerling case 0.

In general, target RCS fluctuation has been modeled using the Chi-square distribution of 2k degrees of freedom:

$$p(\sigma) = \frac{1}{(k-1)!}\frac{k}{\bar{\sigma}}\left(\frac{k\sigma}{\bar{\sigma}}\right)^{k-1} e^{-\frac{k\sigma}{\bar{\sigma}}}, \ \sigma > 0 \qquad (3.4)$$

σ = RCS, the random variable
$\bar{\sigma}$ = mean RCS
$p(\sigma)$ = the pdf of σ

When k=1, it is called a Rayleigh target, the pdf is

$$p(\sigma) = \frac{1}{\bar{\sigma}} e^{-\frac{\sigma}{\bar{\sigma}}}, \ \sigma > 0 \qquad (3.5)$$

With such a pdf, two Swering cases are designated:

Swerling case 1: slow fluctuation on a scan-to-scan basis

Swerling case 2: fast fluctuation on a pulse-to-pulse basis

When k=2, the pdf is

$$p(\sigma) = \frac{4\sigma}{\bar{\sigma}^2} e^{-\frac{2\sigma}{\bar{\sigma}}} \ , \ \sigma > 0 \tag{3.6}$$

Two other Swerling cased are defined:

Swerling case 3: slow fluctuation on a scan-to-scan basis

Swerling case 4: fast fluctuation on a pulse-to-pulse basis

User defined parameters: (for each target)

- $\bar{\sigma}$ = target mean RCS (m^2)
- select one of the five (0 to 4) RCS fluctuation cases

Simulation procedure:

step 1: Simulate the random fluctuating target RCS σ by Monte-Carlo technique, derive the pdf of σ from Gamma (two-parameter) distribution.

$$p(x|a, b) = \frac{1}{b^a \Gamma(a)} x^{a-1} e^{-\frac{x}{b}} \tag{3.7}$$

For Swerling case 1 and 2, $x = \sigma, \ a = 1, \ b = \bar{\sigma}$

For Swerling case 3 and 4, $x = \sigma, \ a = 2, \ b = \bar{\sigma}/2$

step 2: Generate Gamma random variable σ on a scan by scan (case 1 and 2) or a pulse-to-pulse (case 3 and 4) basis.

The random variable and pdf of σ are shown in Fig. 3.2.

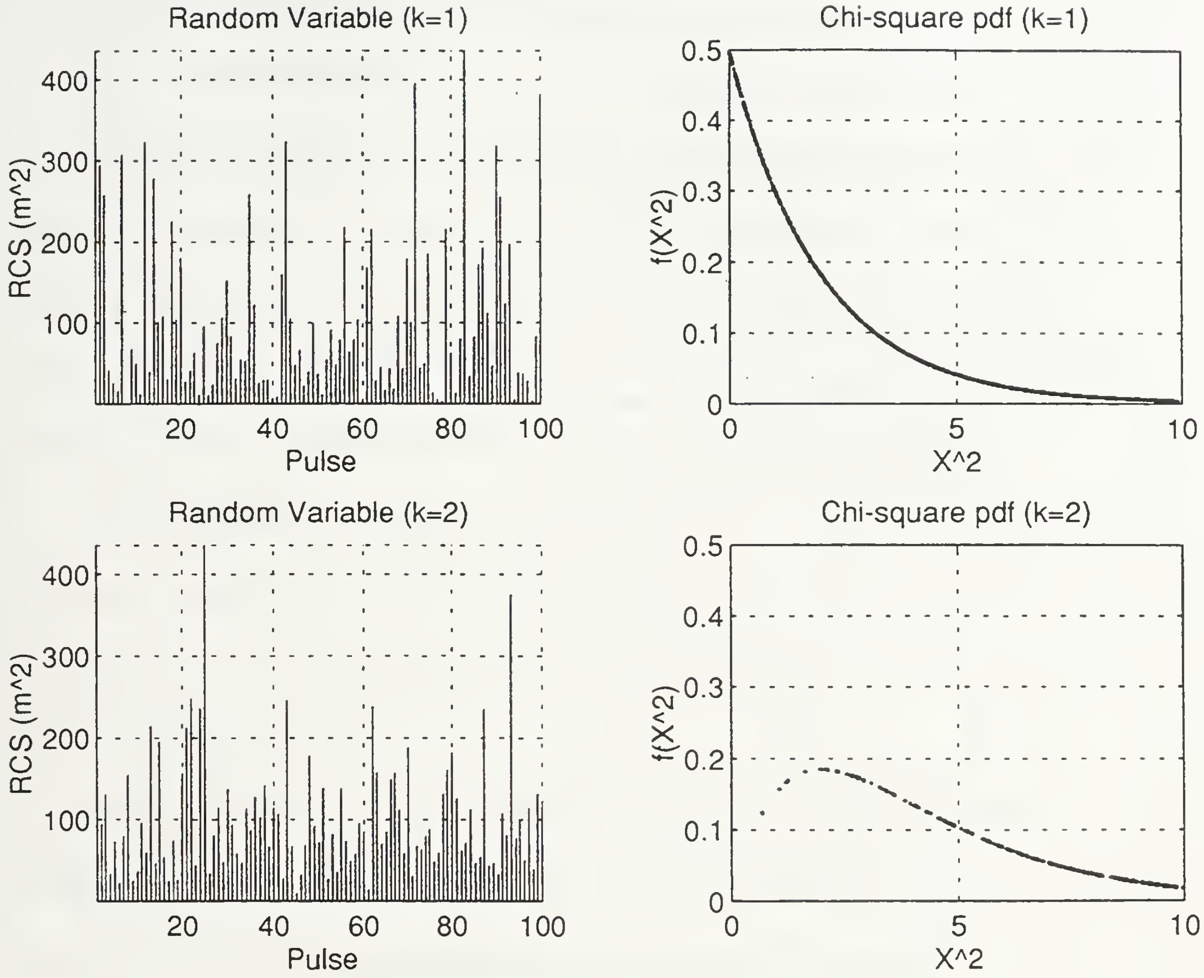


Figure 3.2 Random Variable and pdf of RCS Fluctuation

3. Jammer Characteristics

The simple jammer types and jamming waveforms are specified by user defined parameters as the following and are illustrated in Fig. 3.3.

<u>User defined parameters:</u>

- Jammer Type = 0 : no jammer
  1 : stand-off jammer
  2 : self-screening jammer

- P_j = peak transmit power (kW)
- G_j = antenna gain (dB)
- B_j = bandwidth (MHz)
- f_{rj} = PRF (kHz)
- L_j = loss (dB)
- t_{on} = jamming on time (sec)
- t_{off} = jamming off time (sec)

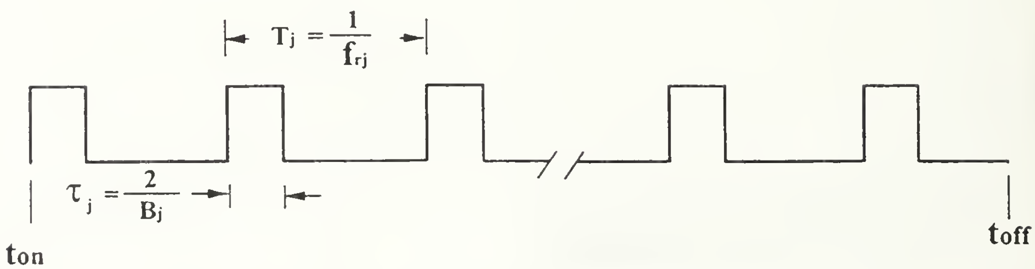


Figure 3.3 Definition of Jamming Signal Waveform

B. RADAR ECHO SIMULATION

1. Echo Simulation

The functional diagram is shown in Fig. 3.4. The simulated radar return is a sum of signals from target echo, jamming signal and clutter returns. The signal amplitude is calculated via the radar range equation, including system plumbing loss, antenna scan variation, simulated system noise and target RCS fluctuation. Signal time delay depends on the target range, and the target return phase depends on the target velocity.

The radar signal is simulated at video frequency and is represented by I and Q values at sampling intervals within the pulse repetition interval (PRI). The sampling interval should be at or a submultiple of the range bin width; this is required to accurately represent the radar echo.

This simulation will generate synthesized radar echoes by using parameters of a specified radar model and a defined scenario. The size of range bin memory array will be determined from the user specified range and scan sector coverages. The simulation procedure is shown in Fig. 3.5, where the range-gated signals are stored in range bins pulse-by-pulse, in accordance with the mainbeam direction.

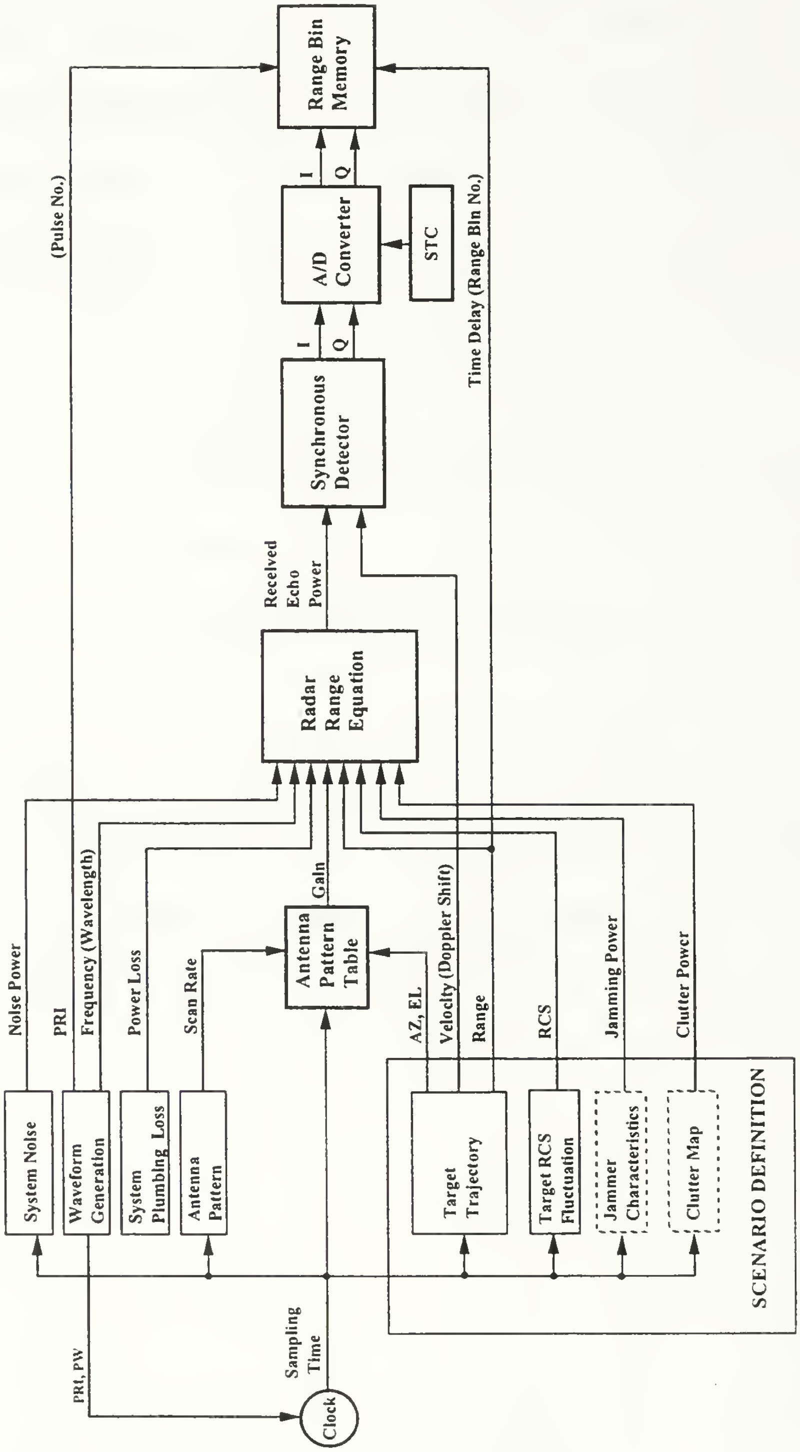


Figure 3.4 Functional Diagram of Radar Echo Simulation

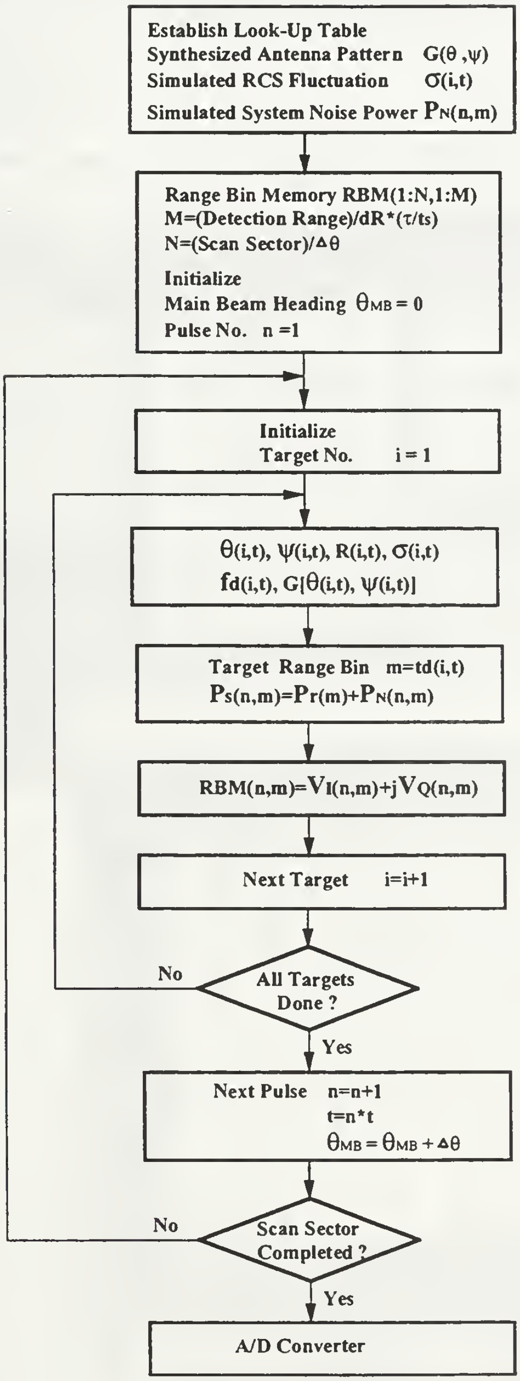


Figure 3.5 Procedure of the Radar Echo Simulation

The parameters of the radar model and a sample scenario definition for use in generating a set of simulated echoes are shown in Fig. 3.6.

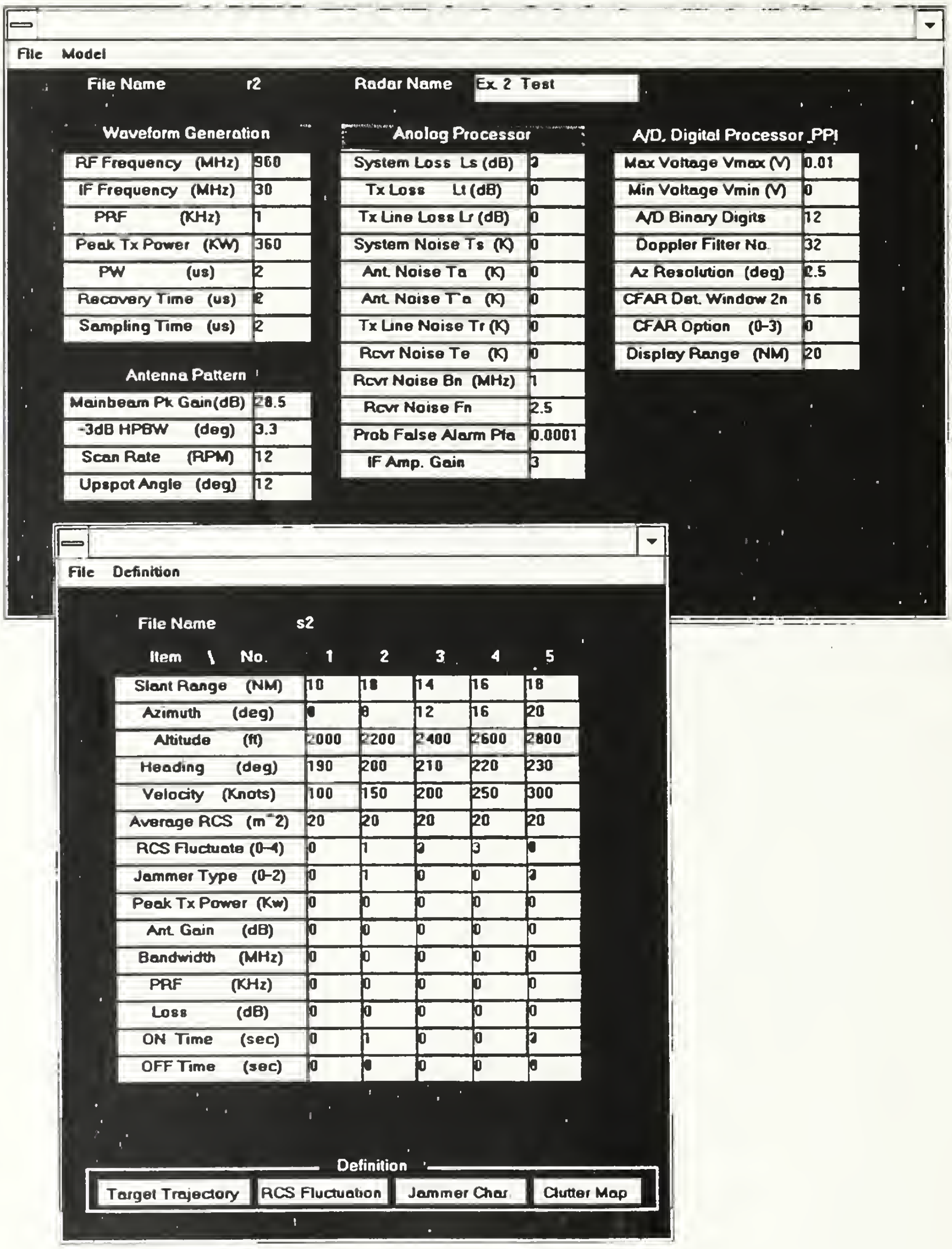


Figure 3.6 Parameters for Radar Echo Simulation

Both the unambiguous range and Doppler frequency are determined by the system parameters: $f_r = 1$ kHz, $\tau = 2$ μs and $f = 900$ MHz ($\lambda = 0.33$ m).

- Unambiguous range ($R_u = c \cdot \tau / 2$)

  $R_u = 150$ km ≈ 81 nmi

- Unambiguous Doppler Frequency f_d and velocity ($v = f_d \cdot \lambda / 2$)

  $-f_r$ (open range) $\leq f_d \leq f_r$ (close range)

  -599.4 km/hr $\leq v \leq 599.4$ km/hr or 323.65 knots $\leq v \leq 323.65$ knots

Both the range and Doppler frequency of a target may be ambiguous. A multiple PRF system will be required to provide the means for their resolution.

The system noise which exists in a radar receiver can be simulated according to the following steps and included into the radar echo simulation.

<u>Simulation procedure:</u>

The system temperature and thermal noise power are first determined by:

$$T_s = T_a + T_r + 10^{(L_r / 10)} \cdot T_e \ (^\circ K) \text{ or by defined value} \tag{3.8}$$

$$P_N = k \cdot T_s \cdot B_n \ \text{(Watts)} \quad \text{or} \tag{3.9}$$

$$P_N = k \cdot T_\circ \cdot B_n \cdot F_n \ \text{(Watts)} \tag{3.10}$$

where k = Boltzmann's constant (°K)
$T_\circ$ = standard temperature (°K)
$T_a \approx 0.876T_a' + 36$ (°K) for an approximately lossless antenna (3.11)
T_a' = simulated noise contribution of solar and galactic source, depending on antenna pointing direction (°K)

The random system noise is then simulated using Monte-Carlo technique according to the following steps:

step 1: Determine the probability density function (pdf) of the I (in-phase) and

Q (quadrature) noise voltage out of the synchronous detectors I_n and Q_n.

$$p(I_n) = \frac{1}{\sqrt{2\pi\sigma_n^2}} e^{-\frac{I_n{}^2}{2\sigma_n^2}} \quad , \quad p(Q_n) = \frac{1}{\sqrt{2\pi\sigma_n^2}} e^{-\frac{Q_n{}^2}{2\sigma_n^2}} \tag{3.12}$$

Where $I_n(t)$ and $Q_n(t)$ are statistically independent Gaussian processes of zero mean $(\mu_n = 0)$ and a variance equal to half the noise power $(\sigma_n^2 = P_N/2)$.

step 2: Generate Gaussian (normal) random signals $I_n(t)$ and $Q_n(t)$.

step 3: The Rayleigh noise voltage output $V_n(t)$ is then obtained by using square-law. The pdf of V_n is $p(V_n)$.

$$V_n(t) = \sqrt{I_n^2(t) + Q_n^2(t)} \tag{3.13}$$

$$p(V_n) = \frac{1}{\sqrt{2\pi\sigma_n^2}} e^{-\frac{V_n{}^2}{2\sigma_n^2}} \tag{3.14}$$

A typical output and pdf of simulated random noise are shown in Figs. 3.7 and 3.8.

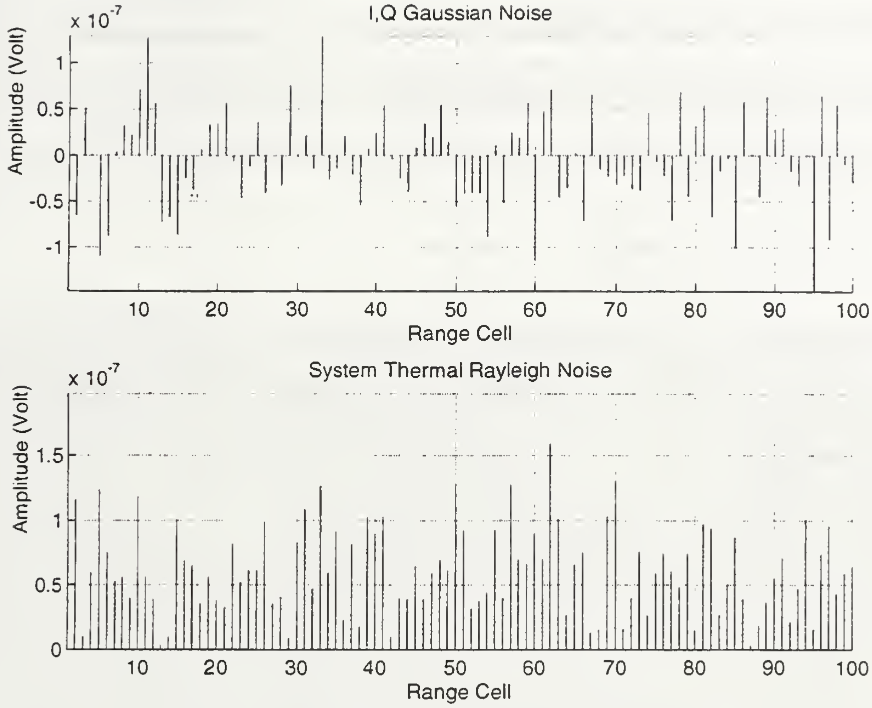


Figure 3.7 Gaussian and Rayleigh Noises

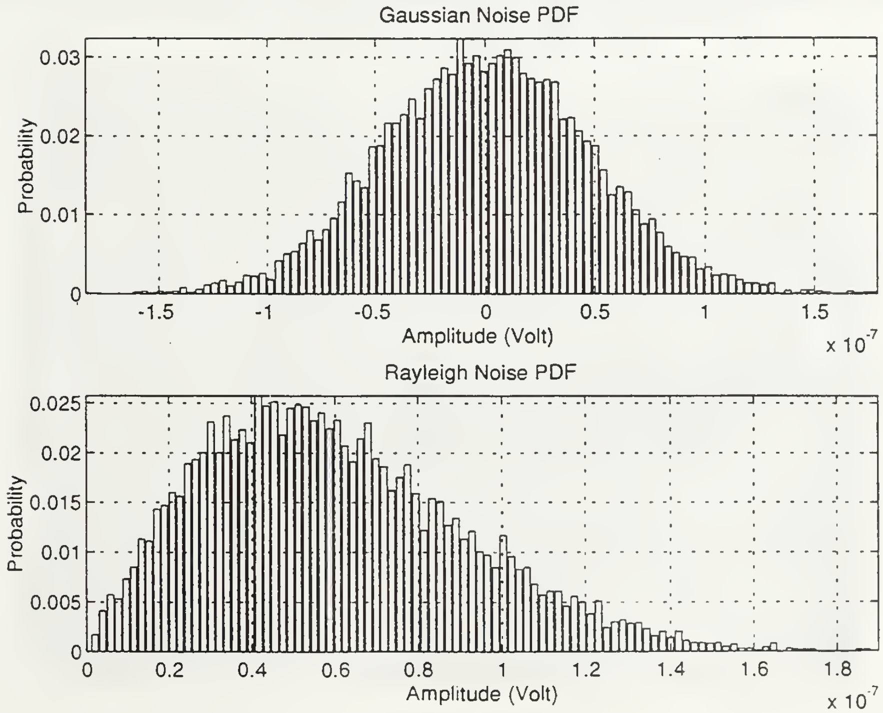


Figure 3.8 Probability Density Function of Random Noises

To achieve a desired probability of false alarm P_{fa}, a constant threshold V_T for system noise depression is derived below and the simulated system thermal noise cell-map is shown in Fig. 3.9.

$$P_{fa} = \int_{V_T}^{\infty} \frac{V_n}{\sigma_n^2} e^{-\frac{V_n{}^2}{2\sigma_n^2}} dV_n = e^{-\frac{V_T{}^2}{2\sigma_n^2}} \tag{3.15}$$

$$V_T = \sqrt{-2\ln(P_{fa})\sigma_n^2} \ \text{(Volts)} \tag{3.16}$$

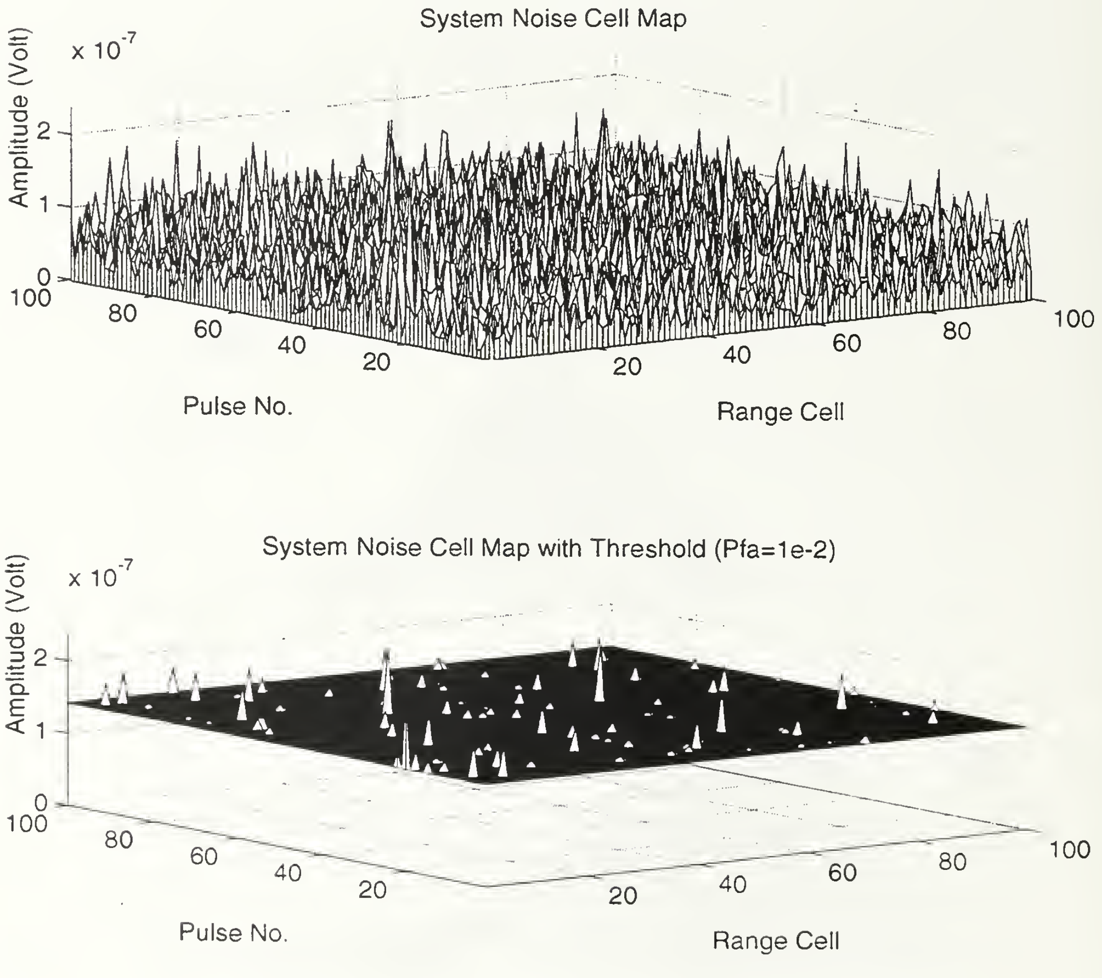


Figure 3.9 Simulated System Thermal Noise

2. Echo Verification

The I and Q values stored in the range bins can be converted to amplitudes and Doppler frequencies. The detected targets can be compared against the defined scenario (Fig. 3.10).

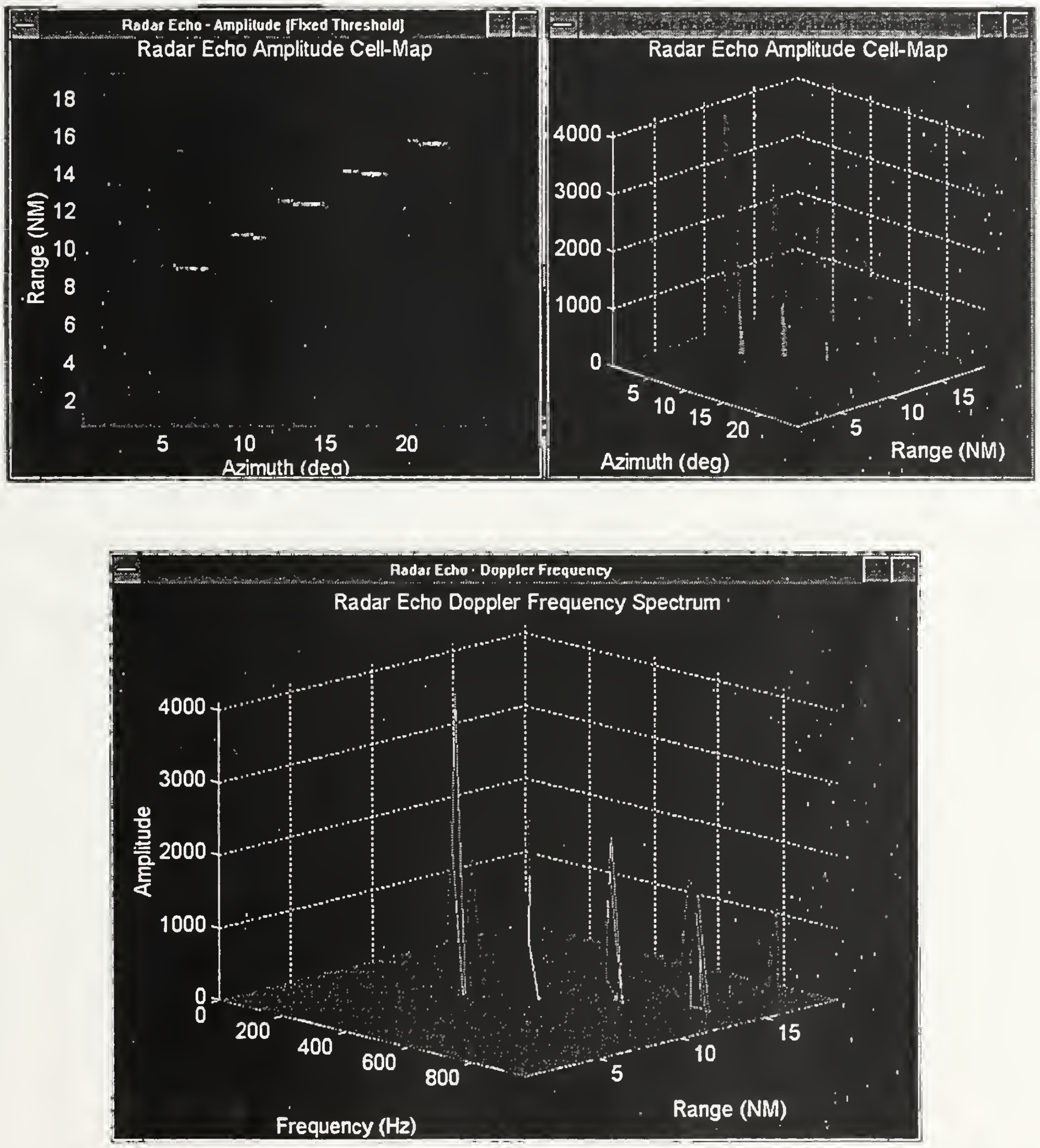


Figure 3.10 Echo Verification by Amplitude over Range, Doppler and Azimuth

C. RADAR PROCESSING SIMULATION

1. Radar Processing

The functional diagram of radar processing simulation is shown in Fig. 3.11. The pulse-by-pulse range-gated I and Q simulated radar echo data have been stored in the range bin array. This data will be processed according to the radar processing sequence defined by this program. The amplitude, Doppler frequency, range and bearing of detected targets will then be sent to the plan position indicator (PPI) unit for display.

2. Control and Display

A PPI unit (Fig. 3.12) presents each of the detected targets in the field of view of the radar as a bright spot on the CRT. Its range and bearing are given by the calibrated distance from the center of the CRT and the azimuth angle on the perimeter.

The simulation of the PPI display is achieved by rotating a range sweep line about the range origin in synchronization with the azimuth scanning of the antenna mainbeam (Fig. 3.13). The various targets then appear as bright blips on the display as the range sweep line rotates over them.

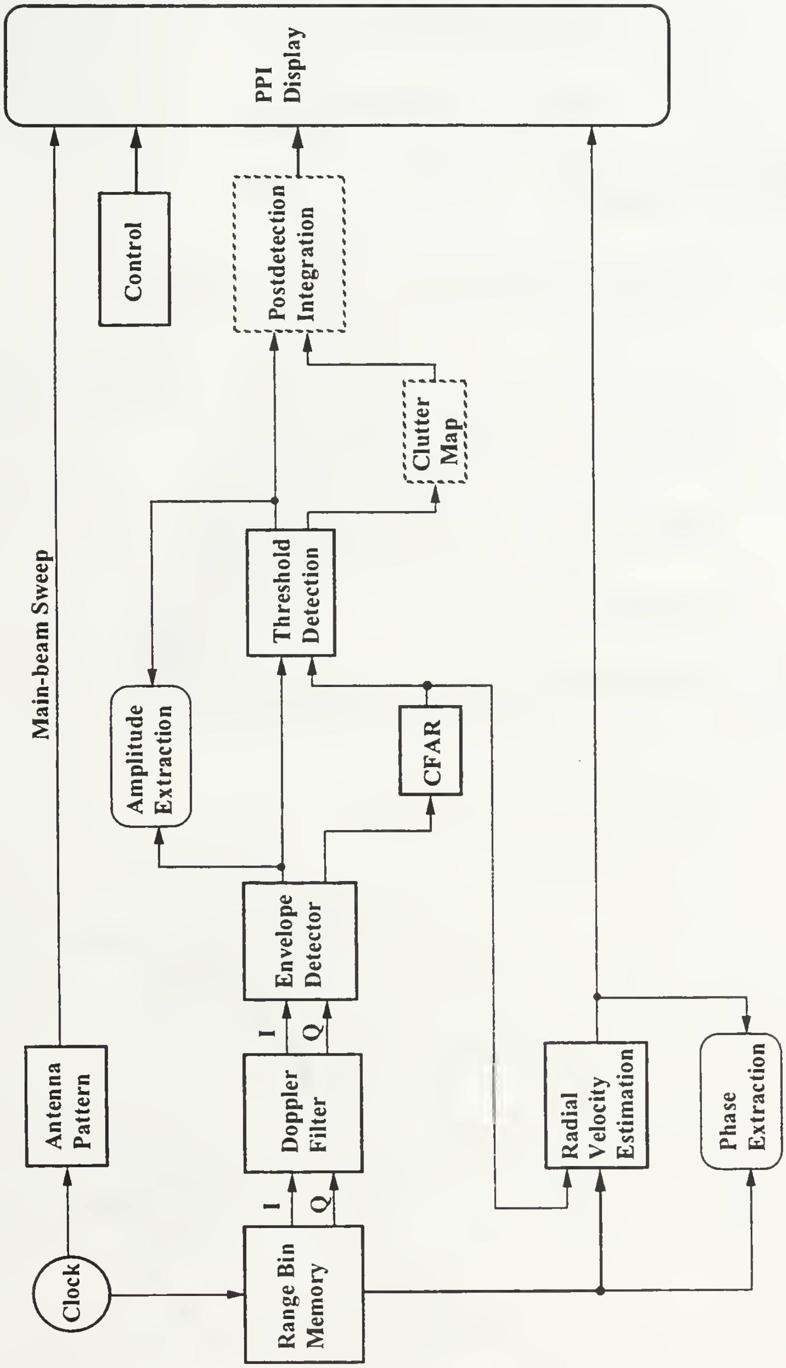


Figure 3.11 Functional Diagram of Radar Processing

User defined parameters:

- R_{dsip} = display range (nmi)
- $d\theta$ = azimuth resolution (degree)

Simulation procedure:

step 1: The simulated PPI display scale is determined by:

- $R_{min} < R_{disp} \leq R_{max}$ (resolution $dR_{disp} = \frac{R_{disp}-R_{min}}{150 \text{ pixels}}$, nmi)
- $0^\circ \leq \theta \leq 360^\circ$ (resolution $d\theta$, degree)
- Range marker ring spacing = $\frac{R_{disp}}{5}$ (nmi)
- Azimuth marker spacing = 1°
- Target radial length = $\max[1, (\frac{150}{M_{disp}})]$ (pixels)

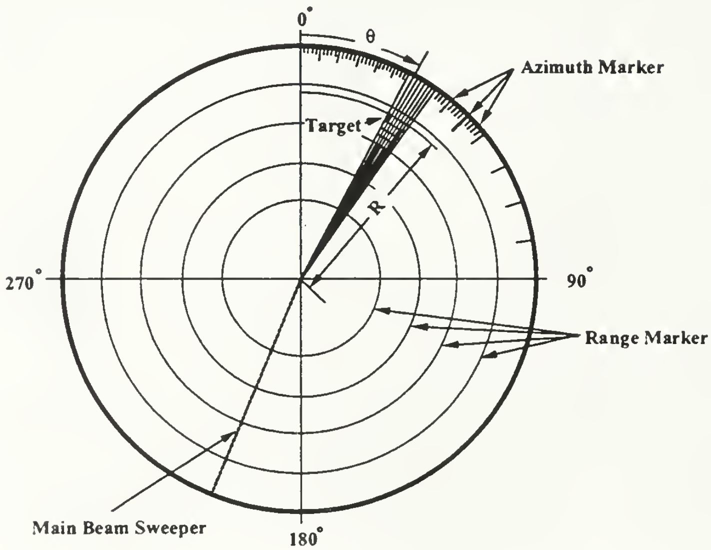


Figure 3.12 Key Elements on a Simulated PPI Display

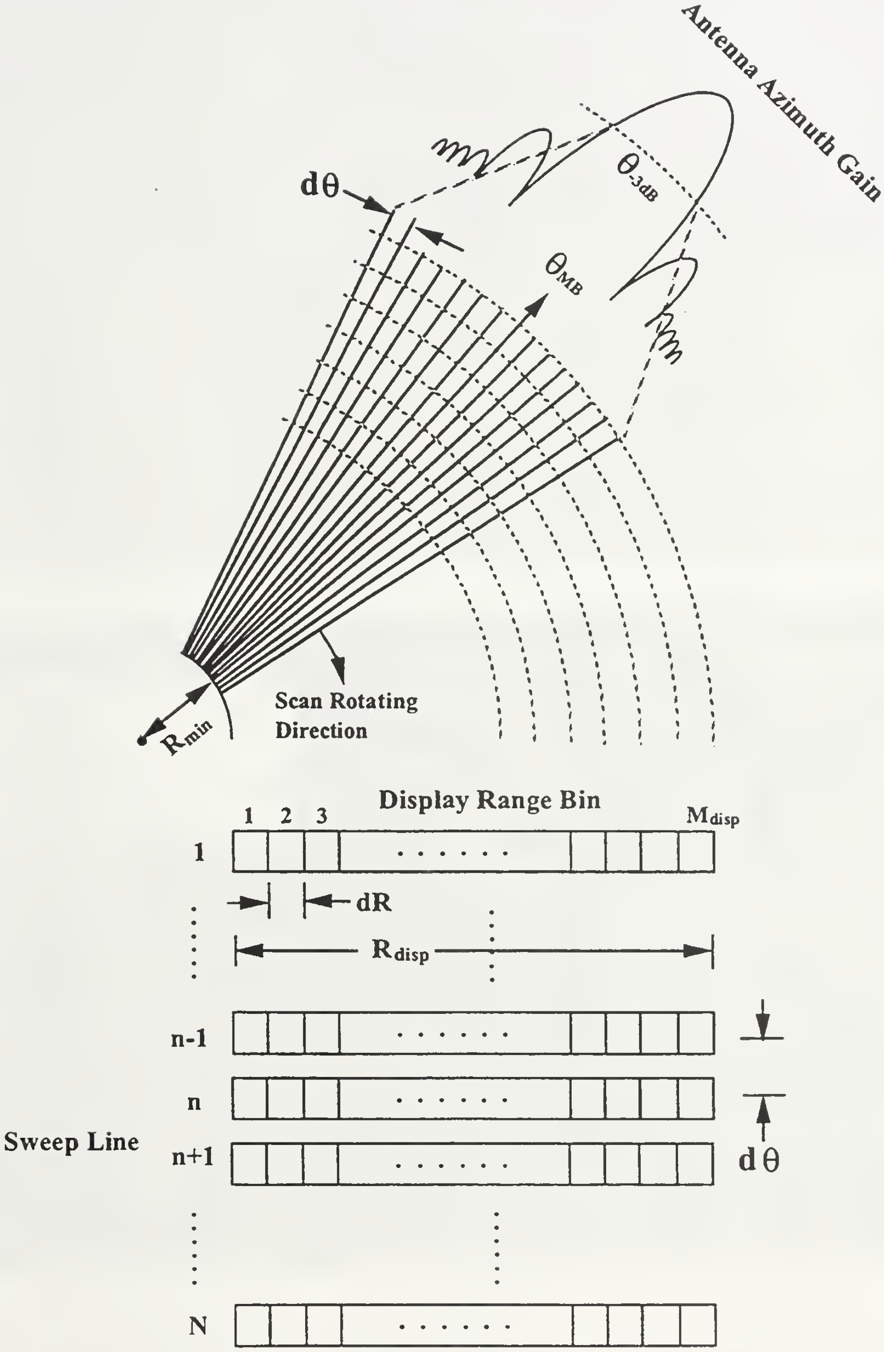


Figure 3.13 Scanning Antenna and Range Bin Array

Fig. 3.14 shows a simulated PPI display. A sample signal from the first target at the 56th range bin and the 11th Doppler bin can be used to illustrate the estimation of its range and velocity as shown below (Fig. 3.15):

- Range estimation

$$R = 56 \cdot dR + R_{min} = 56 \cdot 0.162 + 0.81 = 9.882 \text{ (nmi)} \tag{3.17}$$

- Velocity estimation

$$F_n = (n-1) \cdot f_r / N_f = 10 \cdot 1000/32 = 312.5 \text{ (Hz)} \tag{3.18}$$

$$v = F_n \cdot \lambda/2 = 312.5 \cdot 0.333/2 = 187.3 \text{ (km/hr)} = 101.13 \text{ (knots)} \tag{3.19}$$

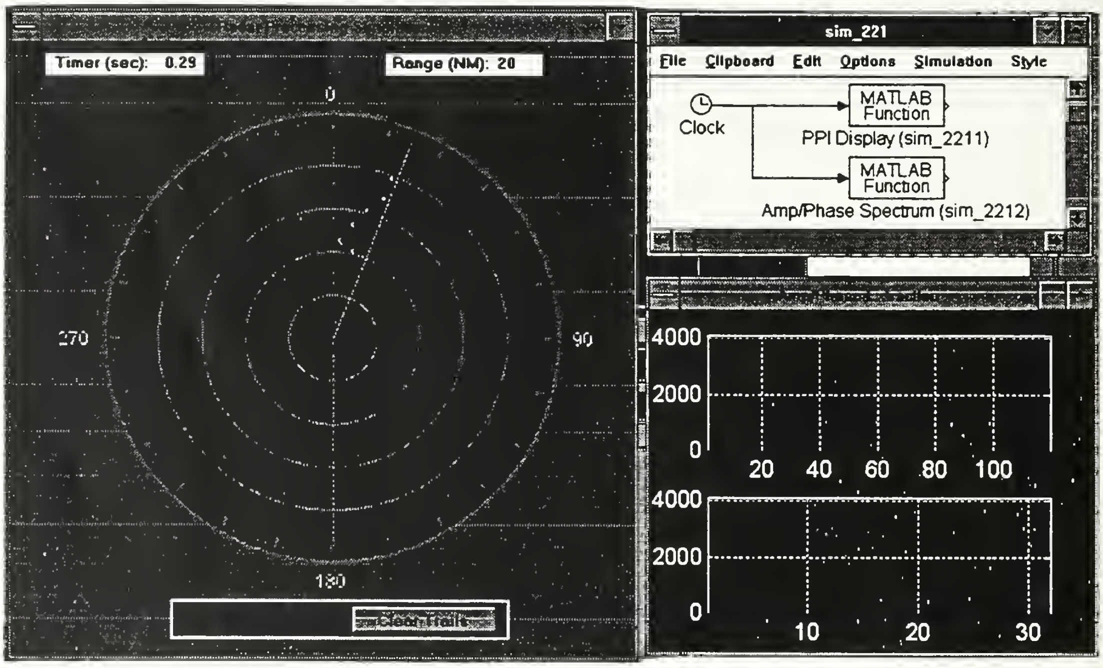


Figure 3.14 Simulated PPI Display for Radar Processing

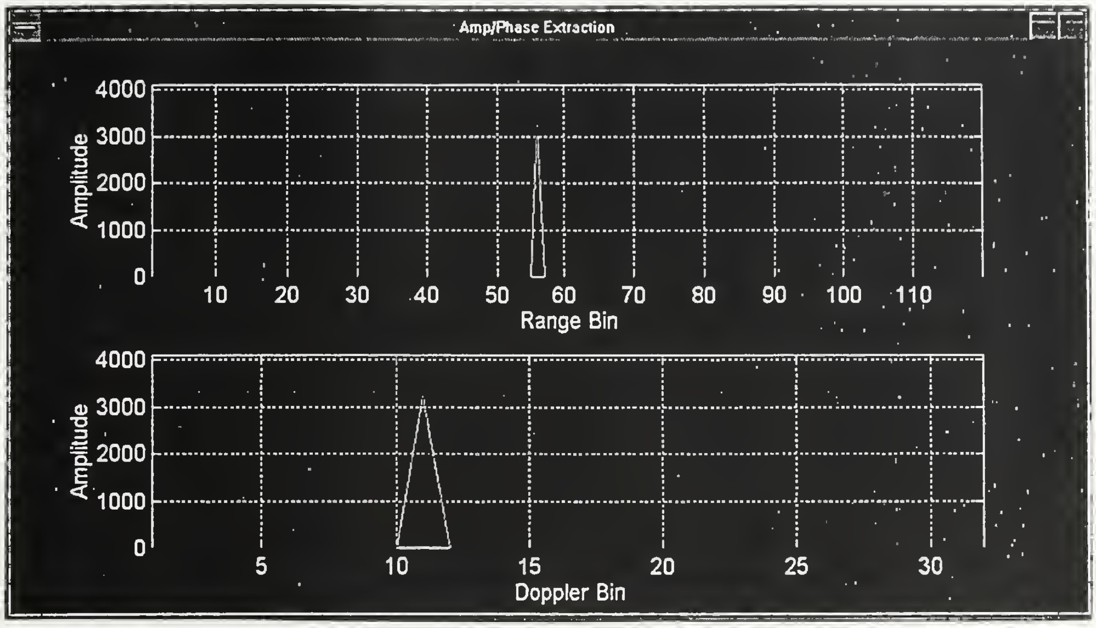


Figure 3.15 Range and Velocity Estimation of a Sampled Target

3. Amplitude as a Function of Range-Doppler-Azimuth

The moving window postdetection integrated amplitude over the range bin, the Doppler bin, and as a function of the pulse number is shown in Fig. 3.16. These different views of the processed signal can be used for radar echo analysis and radar processing evaluation.

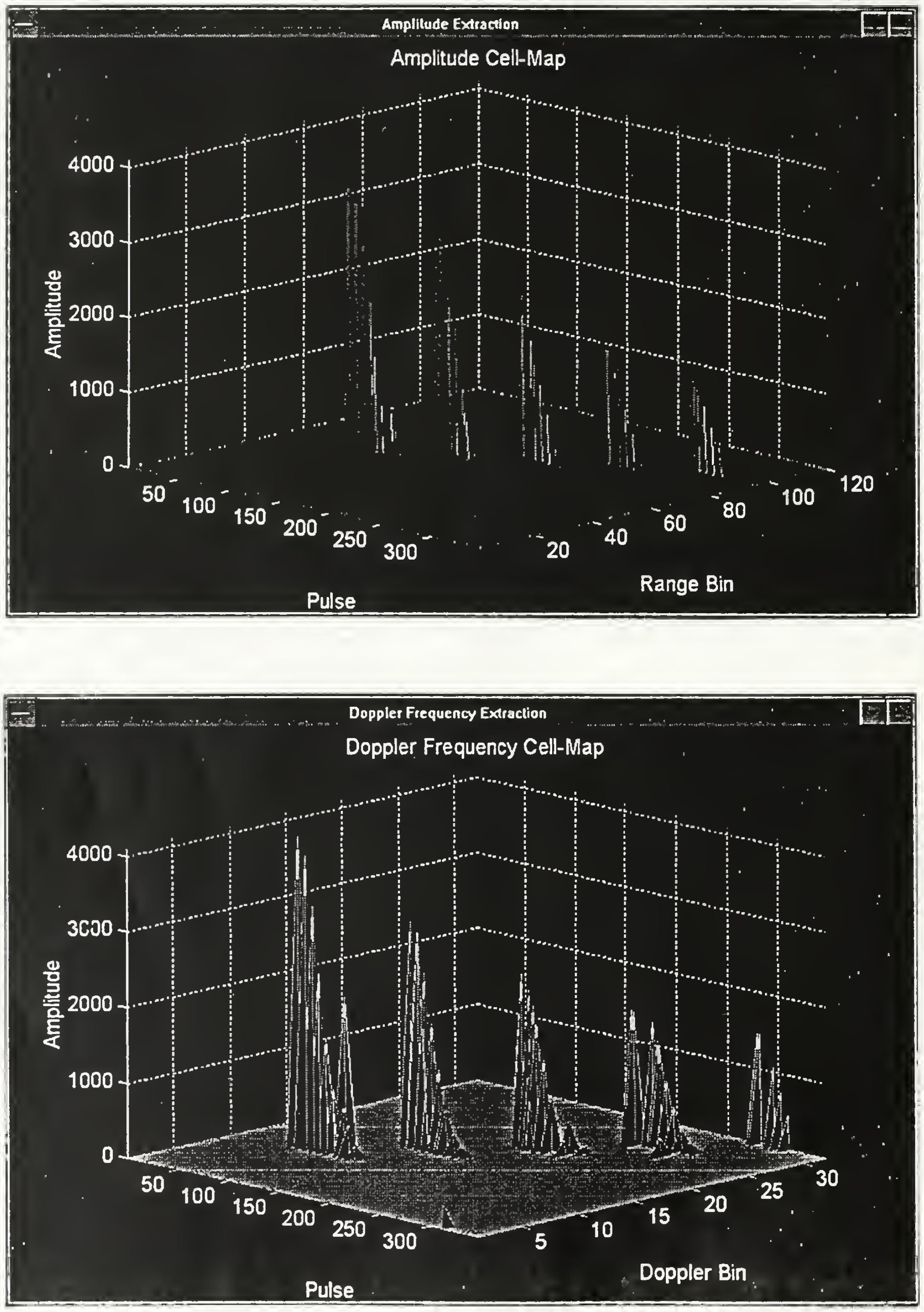


Figure 3.16 Amplitude as a Function of Range-Doppler-Azimuth

IV. DISCUSSION

In this thesis, a radar modeling and simulation software to use under SIMULINK has been completed. It is an initial attempt to construct standardized validated models of surface based operational radars for performance evaluation and for the development of upgrades or new systems.

The modeling begins with the IF filter signal output, with simulated system noise added at that point. To simulate that signal, digitized azimuth and elevation antenna radiation patterns have been included in the model. This creates the possibility of interacting with 3D ground mapping data to define the radar operating environment from location to location and from time to time, thereby builds and updates the clutter map.

The computer will be hard pressed to move a step further to model complicated waveform and IF filtering such as pulse compression. For example, at a bandwidth of 30 MHz, the data rate must be at least 60 MHz and 120 MHz will be preferred. A dedicated processor will be needed for this purpose except for the most powerful workstations available today. Utilization of specialized waveform generation hardware for this purpose should be considered.

Several desirable aspects of radar operations have not been included in this work. Among them the multiple PRF capability and range-Doppler ambiguity resolution; ECCM features such as carrier frequency agility and sidelobe cancellation; clutter map for enhanced zero velocity target detection are the ones to be considered for implementation in the immediate future.

APPENDIX A. USER'S MANUAL

A. INTRODUCTION

Radar Modeling and Simulation (RMS) is a program, which integrates Search Radar Model, Scenario Definition, Radar Echo Simulation and Radar Processing Simulation functions under a Graphical User Interface environment.

Search Radar Model and Scenario Definition have two uses: model definition and model verification. The user starts by either defining a new model or recalling a previously defined model, and then proceeds to verifiy that model. In practice, these two steps are often performed iteratively, as the user creates and modifies a model to achieve the desired behavior.

Radar Echo Simulation integrates a defined radar model and a defined scenario to radar echo generating in range bin memory format and then proceeds to verify that simulated radar echo and save for future uses.

Radar Processing Simulation loads a simulated radar echo and evaluates the radar performance through PPI display and signal extraction, while the simulation is running.

RMS has all the same system requirements as the MATLAB version 4.2c.1 and SIMULINK version 1.3. In addition, RMS requires Statistics, Signal Processing and Animation Toolboxes for use with MATLAB.

B. QUICK START

This section describes a short series of actions for the user to start RMS.

1. Double-click the MATLAB icon to invoke the MATLAB command window. Enter the command **rms** at the MATLAB prompt to open the Radar Modeling and Simulation main menu.
2. Click the **Search Radar Model** pushbutton from the main menu to open a Search Radar Model worksheet.
3. Select **Open...** from the **File** menu bar to open a defined radar model named **r1** and review the radar parameters.
4. Select either **Antenna Pattern** from the **Model** menu bar or click **Antenna Pattern** pushbutton on the worksheet to verify the antenna radiation patterns. Repeat to verify the simulated system noise by selecting **System noise**.
5. Click the **Scenario Definition** pushbutton from the main menu to open a Scenario Definition worksheet.
6. Select **Open...** from the **File** menu bar to open a defined scenario named **s1** and review the scenario parameters.
7. Select either **RCS Fluctuation** from the **Definition** menu bar or click **RCS Fluctuation** pushbutton on the worksheet to verify the simulated target RCS fluctuation.
8. Click the **Radar Echo Simulation** pushbutton from the main menu to open a Radar Echo Simulation worksheet.
9. Select **Open...** from the **File** menu bar to open a defined radar model named **r1** and a defined scenario named **s1**.

10. Select either **Echo Simulation** from the **Simulation** menu bar or click **Echo Simulation** pushbutton on the worksheet, then wait until the simulation is completed.
11. Select either **Amp. (Fixed Threshold)** from the **Simulation - Echo Verification** menu bar or click **Amp. (Fixed Threshold)** pushbutton on the worksheet to verify the radar echo amplitude cell-map.
12. Select **Save...** from the **File** menu bar to save the simulated radar echo to **e1**.
13. Click the **Processing Simulation** pushbutton from the main menu to open a Radar Processing Simulation worksheet.
14. Select **Open...** from the **File** menu bar to open a simulated radar echo named **e1**.
15. Select either **Radar Processing** from the **Simulation** menu bar or click **Radar Processing** pushbutton on the worksheet, then wait until the processing is completed.
16. Select either **Control & Display** from the **Simulation** menu bar or click **Control & Display** pushbutton on the worksheet to open a simulated PPI display and a SIMULINK window for simulation control.
17. Run a radar processing simulation by selecting **Start** from the **Simulation** menu bar on the SIMULINK window. While a simulation is running, the processing result will be displayed on the simulated PPI display and scopes.

C. TUTORIAL

1. Radar Modeling and Simulation Main Menu

Double-click the MATLAB icon to invoke the MATLAB command window (Fig. A.1). Enter the command `rms` at the MATLAB prompt to open the Radar Modeling and Simulation main menu (Fig. A.2).

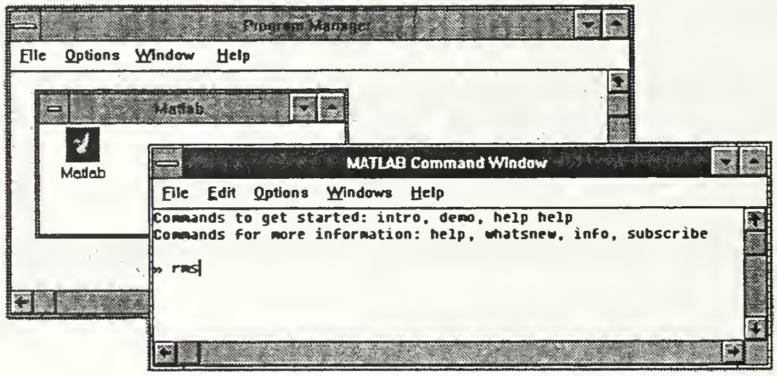


Figure A.1 MATLAB Command Window

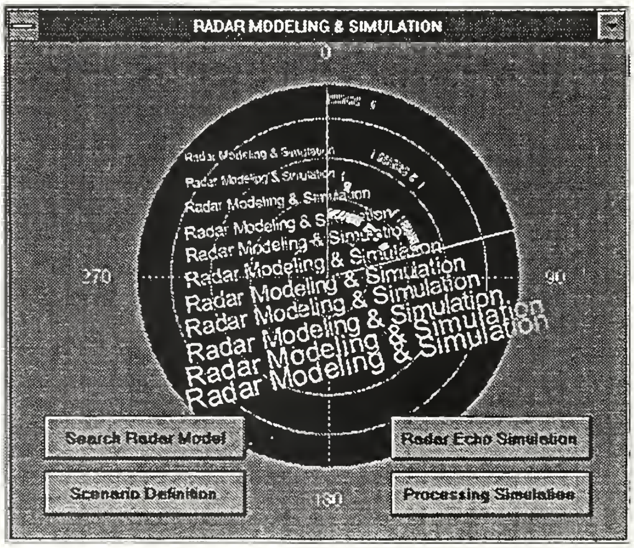


Figure A.2 Radar Modeling and Simulation Main Menu

2. Search Radar Model Worksheet

Click the **Search Radar Model** pushbutton from the main menu to open a Search Radar Model worksheet (Fig. A.3). The white color single line allows the user to enter a string value to be used by the application. The user can accept, edit, delete, or replace an editable text value. A carriage return must follow the last string value entered.

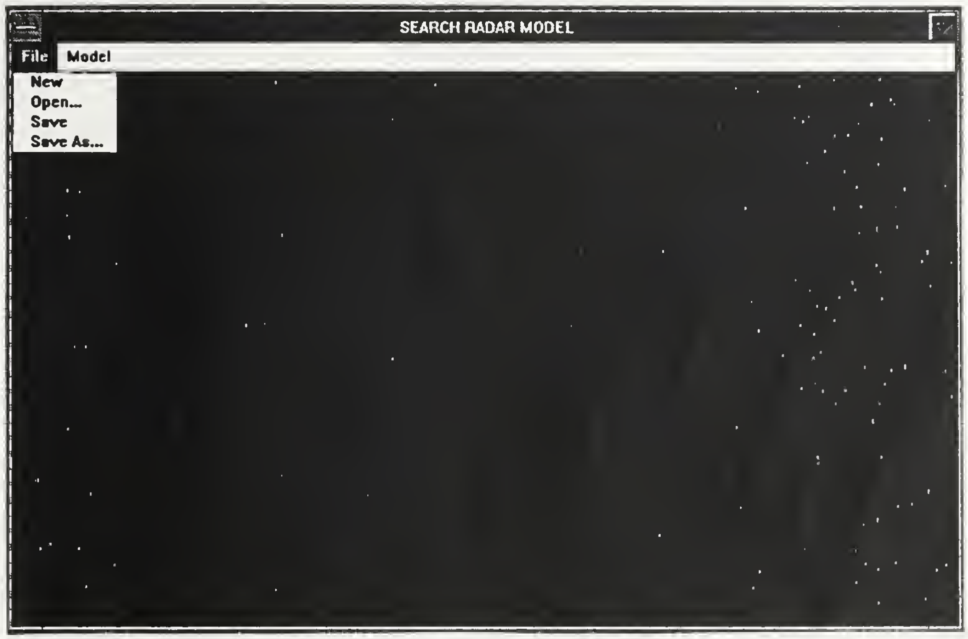


Figure A.3 Search Radar Model Worksheet

a. File

The user can use this function by selecting from the **File** menu bar to create and save a new radar model or open a defined radar model and save it after modification.

Select **New** to create a new radar model (Fig. A.4).

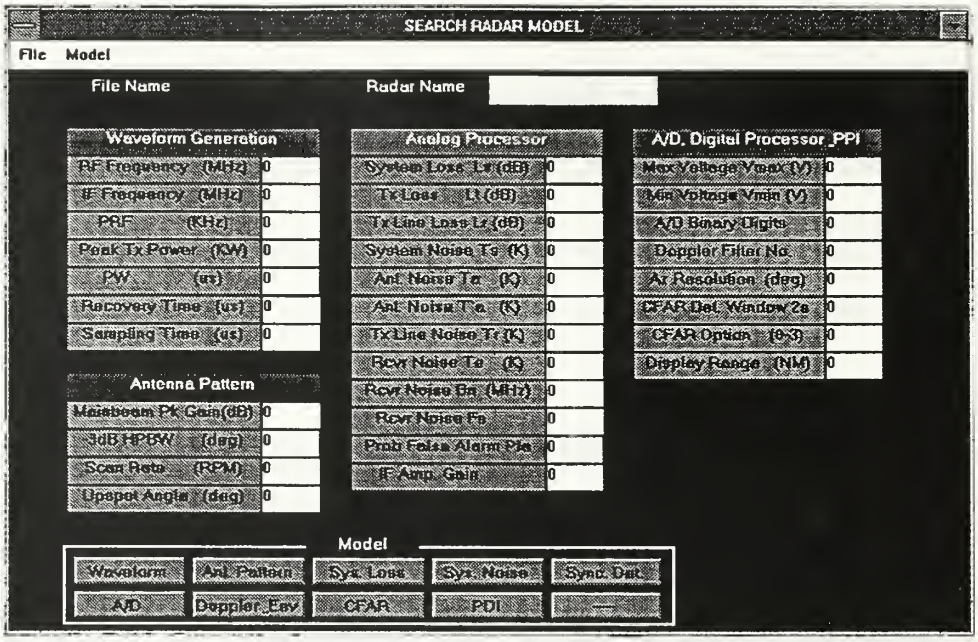


Figure A.4 Create a New Radar Model

Select **Open...** to open a defined radar model by entering a desired file name (Fig. A.5).

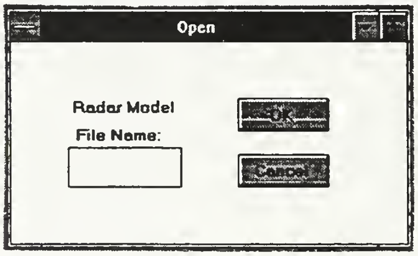


Figure A.5 Open a Defined Radar Model

Select **Save** to update a current defined radar model to the same file after modification.

Select **Save As...** to save current radar model by entering a desired file name (Fig. A.6).

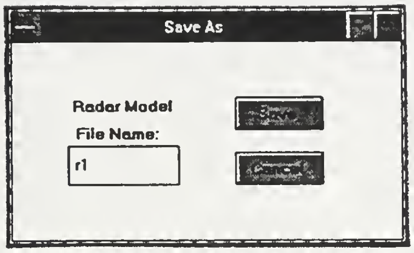


Figure A.6 Save a Radar Model

b. Model

The user can use this function by either selecting from the **Model** menu bar or clicking pushbutton on the worksheet to verify the radar model (Fig. A.7).

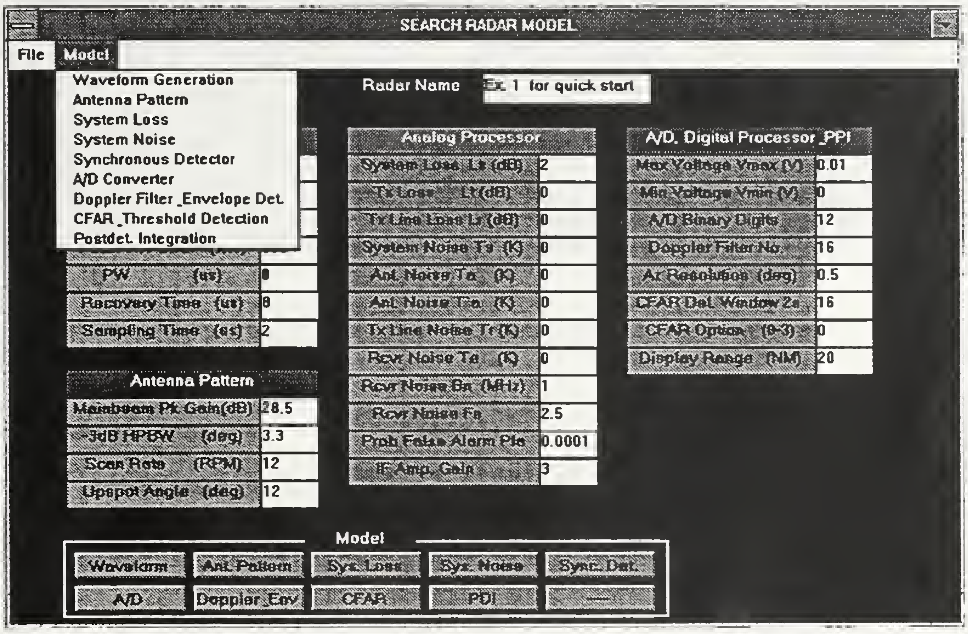


Figure A.7 Radar Model Verification Functions

Select **Waveform Generation** to verify the radar waveform (not available).

Select **Antenna Pattern** to verify the digitized azimuth and elevation radiation patterns of a search radar reflector antenna (Fig. A.8).

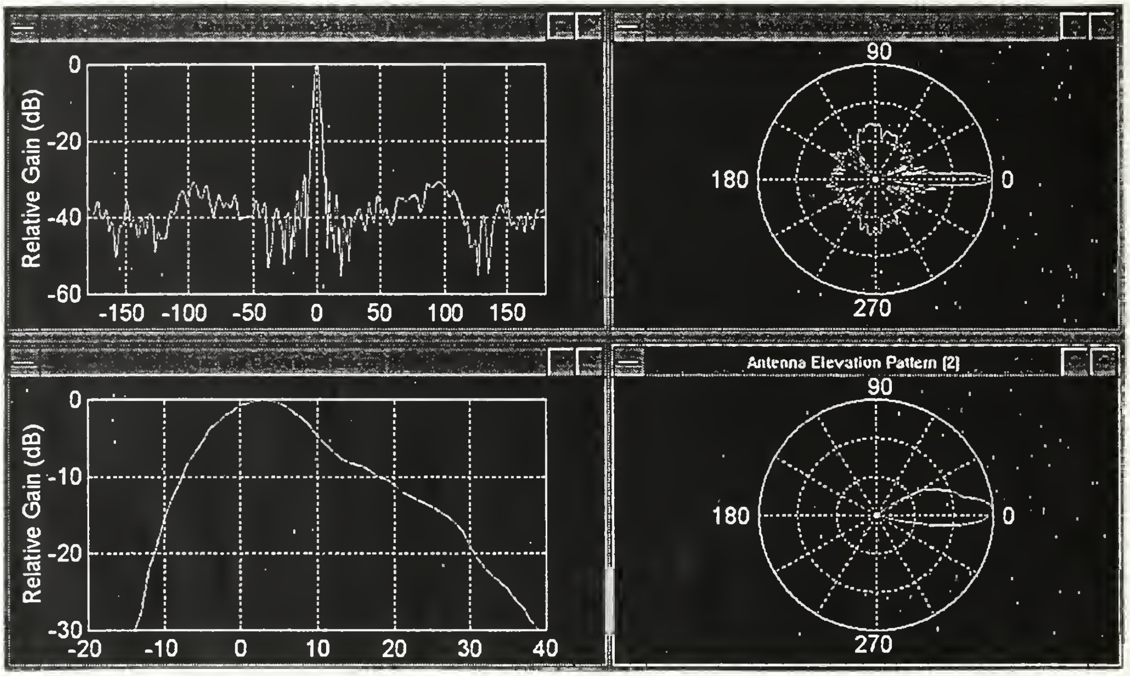


Figure A.8 Digitized Antenna Radiation Patterns

Select **System Loss** to verify the system loss (not available).

Select **System Noise** to verify the simulated random signal and pdf of system thermal noise (Fig. A.9).

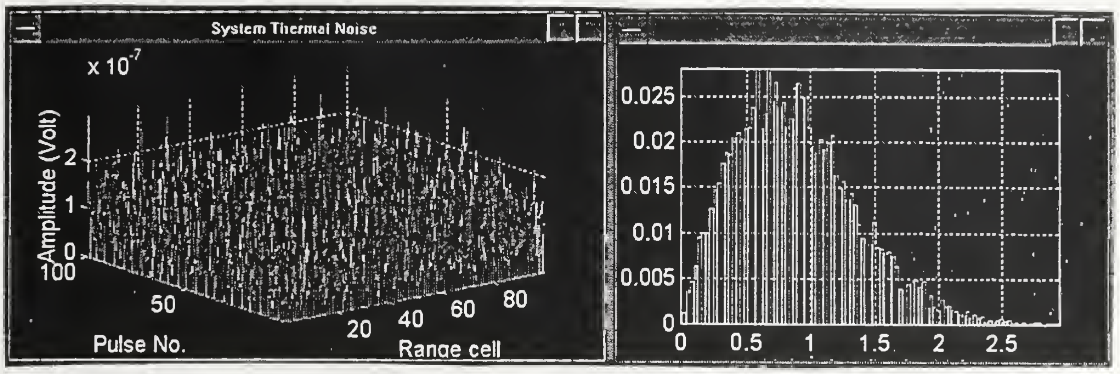


Figure A.9 Simulated System Thermal Noise

Select **Synchronous Detector** to verify the function of Synchronous Detector by running a SIMULINK model. Select **Start** from the **Simulation** menu bar on the SIMULINK window (Fig. A.10), the I and Q video signal waveforms will be displayed on related scopes (Fig. A.11).

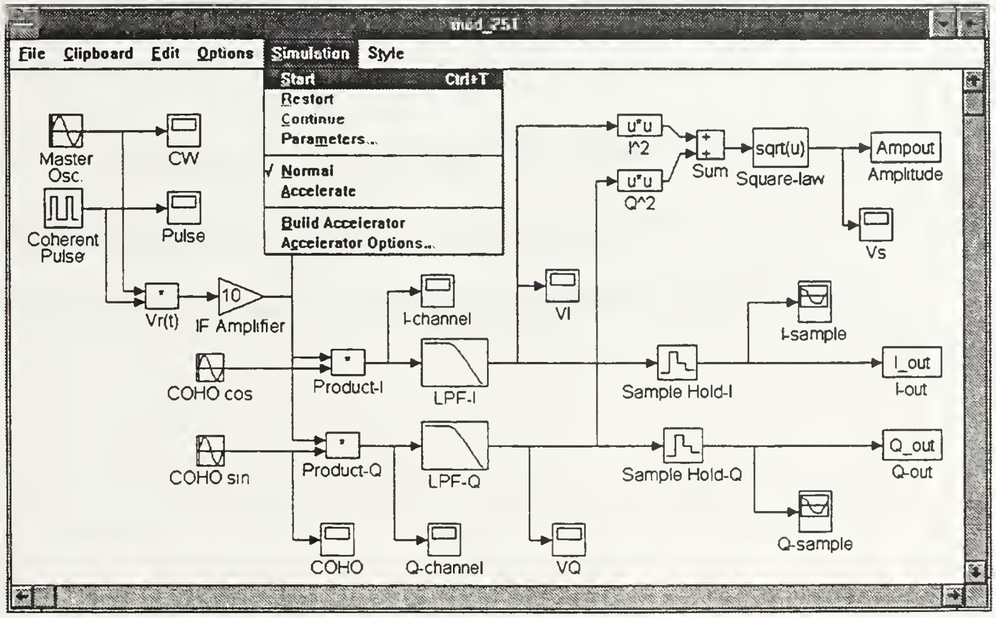


Figure A.10 The SIMULINK Synchronous Detector Model

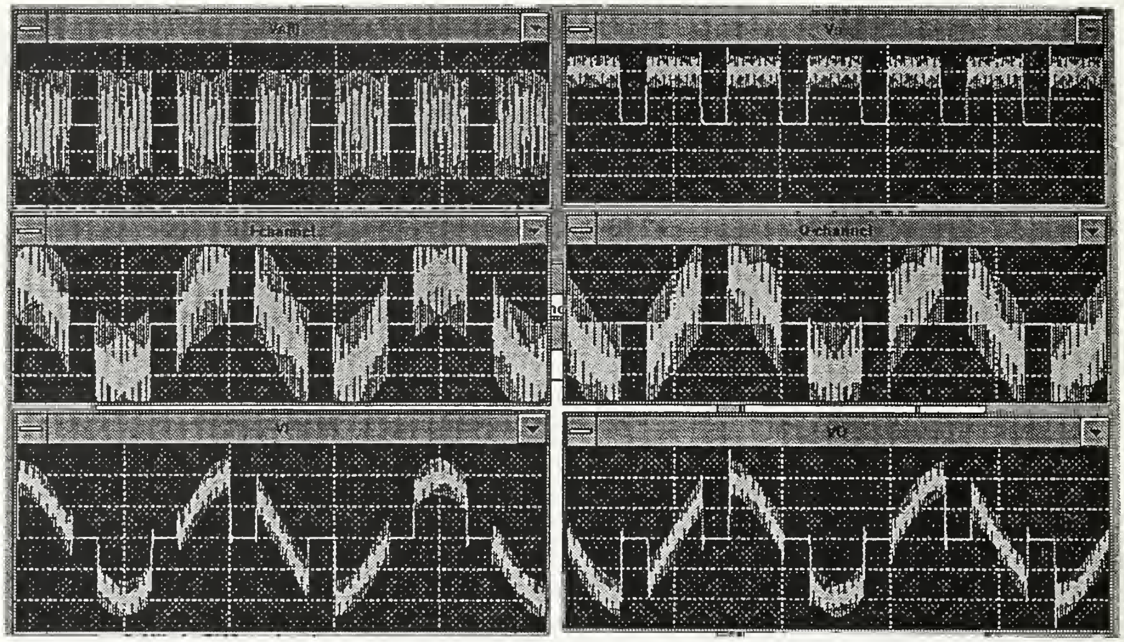


Figure A.11 Simulated Signals of Synchronous Detector Model

Select **A/D Converter** to verify the model of A/D Converter (not available).

Select **Doppler Filter & Envelope Detector** to verify the model of Doppler Frequency FFT processing and square-law amplitude estimation (not available).

Select **CFAR & Threshold Detection** to verify the model of CFAR threshold (Fig. A.12).

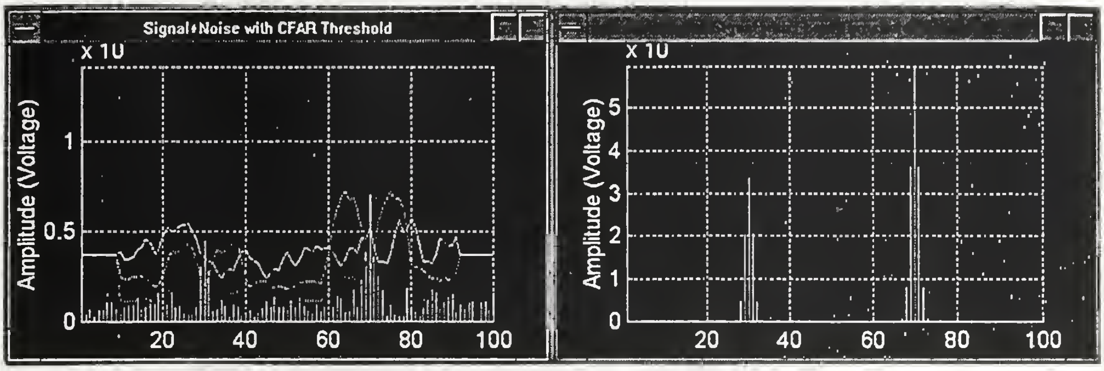


Figure A.12 CFAR and Threshold Detection Model

Select **PDI** to verify the model of Postdetection Integration (not available).

3. Scenario Definition Worksheet

Click the **Scenario Definition** pushbutton from the main menu to open a Scenario Definition worksheet (Fig. A.13).

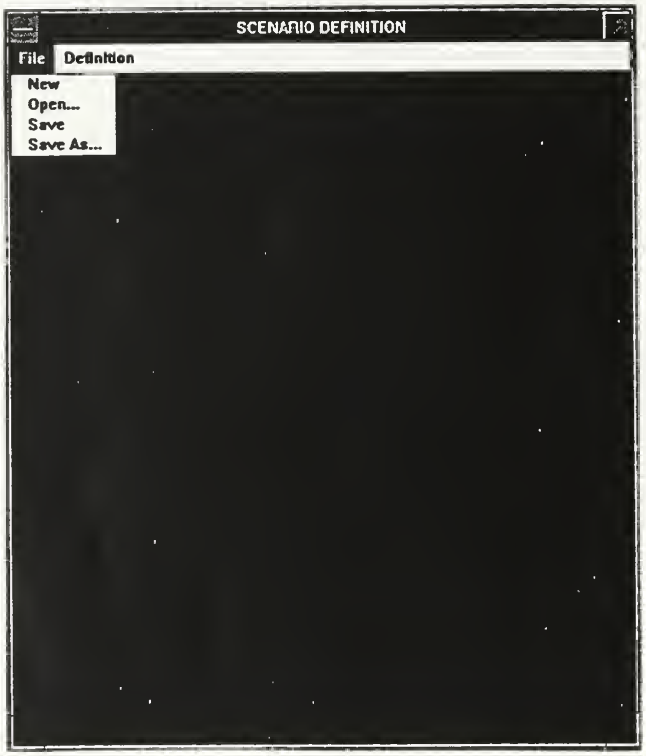


Figure A.13 Scenario Definition Worksheet

a. File

The user can use this function by selecting from the **File** menu bar to create and save a new scenario or open a defined scenario and save it after modification.

Select **New** to create a new scenario (Fig. A.14).

Select **Open...** to open a defined scenario by entering a desired file name (Fig. A.15).

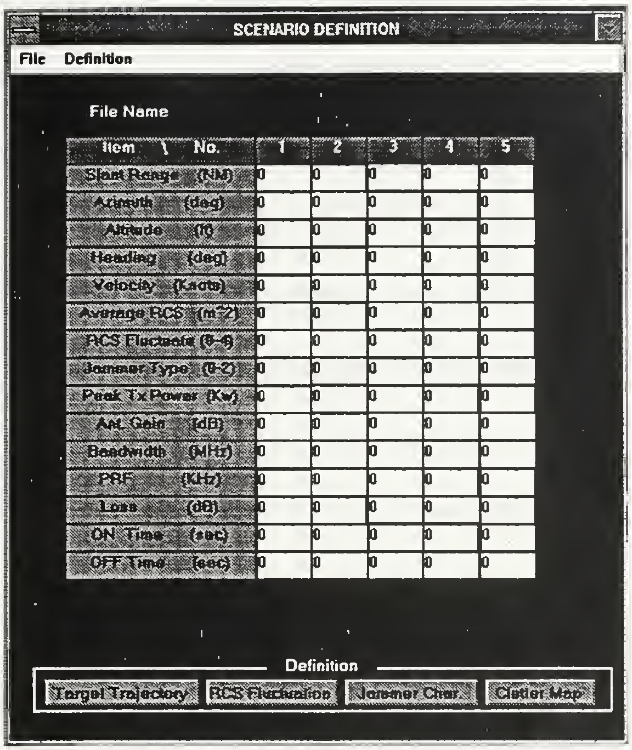


Figure A.14 Create a New Scenario Definition

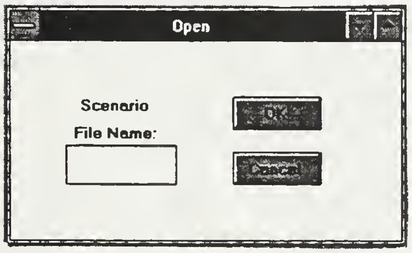


Figure A.15 Open a Defined Scenario Definition

Select **Save** to update a current defined scenario to the same file after modification.

Select **Save As...** to save current scenario by entering a desired file name (Fig. A.16).

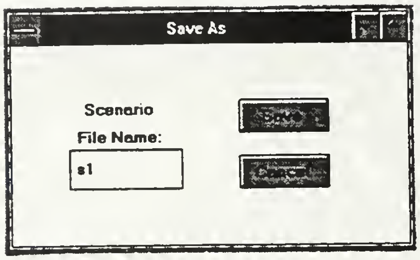


Figure A.16 Save a Scenario Definition

b. Definition

The user can use this function by either selecting from the **Definition** menu bar or clicking pushbutton on the worksheet to verify the scenario definition (Fig. A.17).

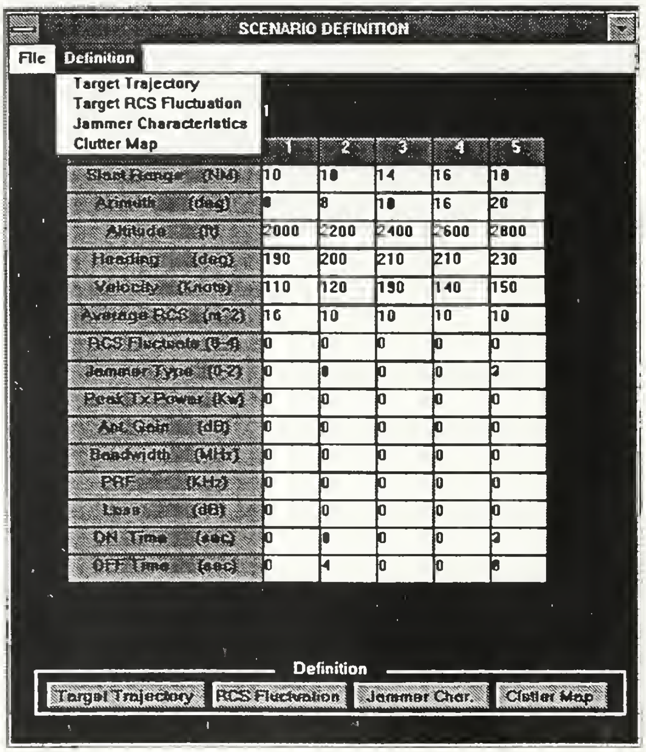


Figure A.17 Scenario Verification Functions

Select **Target Trajectory** to open a simulated PPI display and a SIMULINK simulation control window in order to verify the time-varying target trajectory (Fig. A.18). Run a target trajectory simulation by selecting **Start** from the **Simulation** menu bar on the SIMULINK window. While a simulation is running, the **Start** menu item becomes **Stop**. If the user selects **Stop**, the menu displays **Start** again. The spot color for target, stand-off jammer and self-screening jammer is designated green, yellow and red respectively. The **Show Trail** and **Clear Trail** pushbuttons on PPI display are used for the remaining and clearing target moving trajectory on PPI screen. The simulation time period and step are set by start and stop **Parameters** from the **Simulation** menu bar on the SIMULINK window.

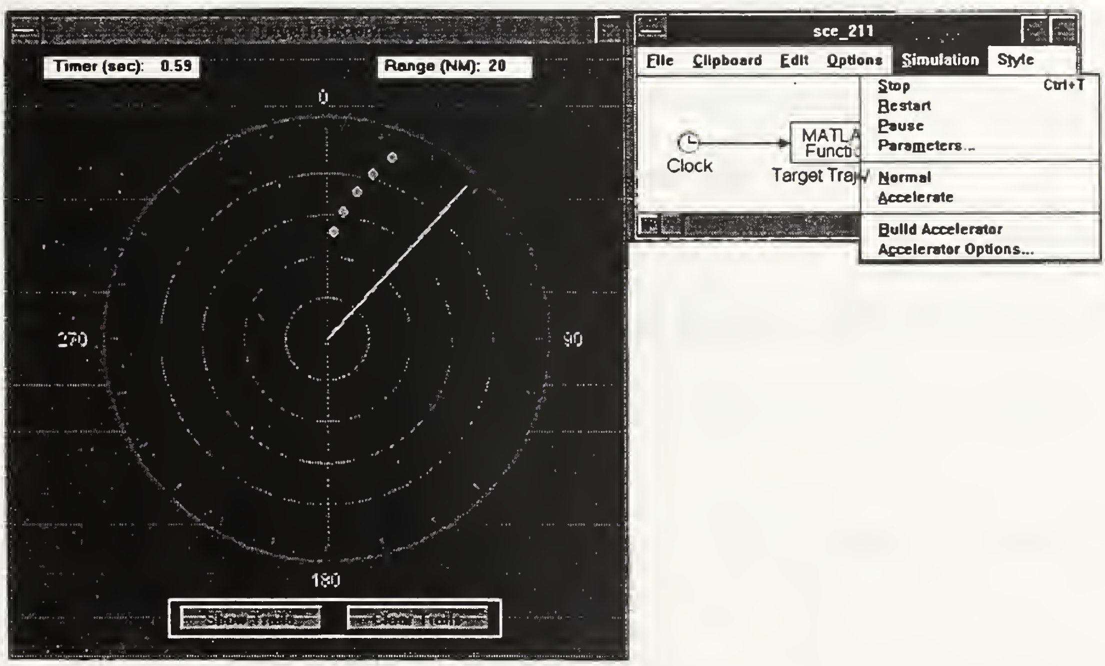


Figure A.18 Target Trajectory Simulation

Select **Target RCS Fluctuation** to verify the simulated RCS fluctuation (Fig. A.19).

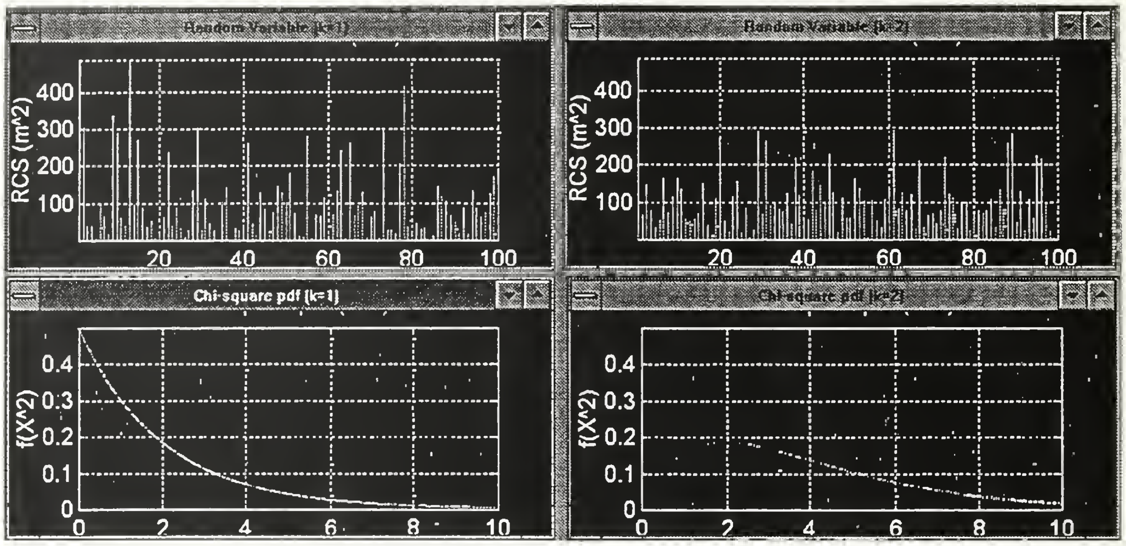


Figure A.19 Simulated RCS Fluctuation

Select **Jammer Characteristics** to verify waveform of jamming signals (not available).

Select **Clutter Map** to verify the simulated clutter map (not available).

4. Radar Echo Simulation Worksheet

Click the **Echo Simulation** pushbutton from the main menu to open a Radar Echo Simulation worksheet (Fig. A.20).

Figure A.20 Radar Echo Simulation Worksheet

a. File

The user can use this function by selecting from the **File** menu bar to open a defined radar model and scenario file for radar echo simulation and save the simulated radar echo.

Select **Open...** to open a defined radar model and scenario by entering two desired file names (Fig. A.21).

Select **Save As...** to save current simulated radar echo by entering a desired file name (Fig. A.22).

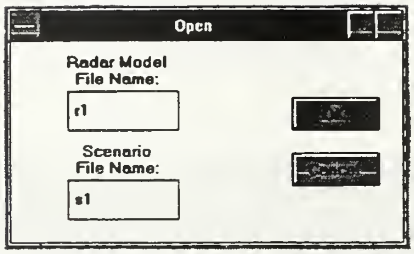


Figure A.21 Open Defined Radar Model and Scenario Definition

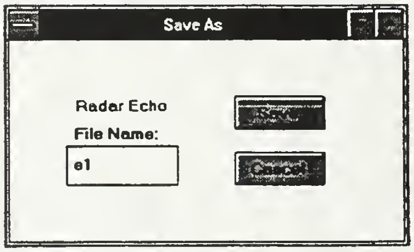


Figure A.22 Save a Simulated Radar Echo

b. Simulation

The user can use this function by either selecting from the **Simulation** menu bar or clicking pushbutton on the worksheet to simuate and verify the radar echo, in accordance with user specified coverage.

Select **Echo Simulation** to integrate the specified radar model and scenario and generate a corresponding radar ccho. The user can monitor the simulation status from a slider box (Fig. A.23). The echo verification functions will be provided when the simulation is complete (Fig. A.24).

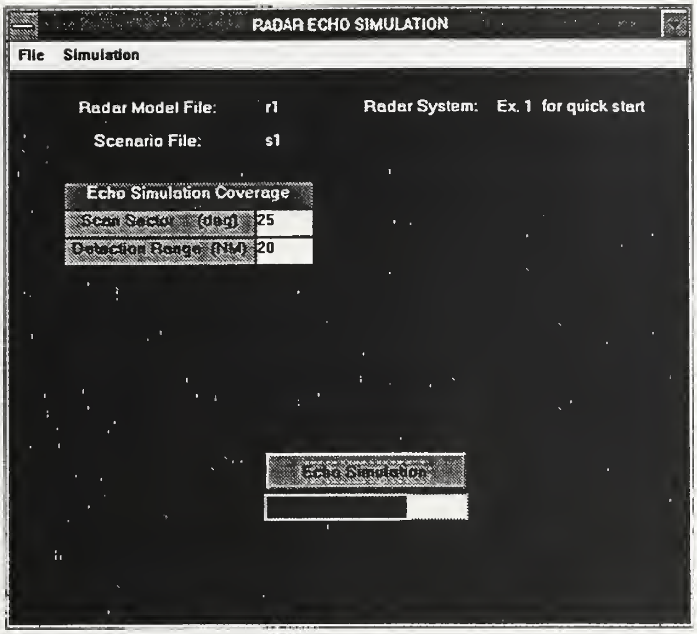


Figure A.23 Radar Echo Simulation

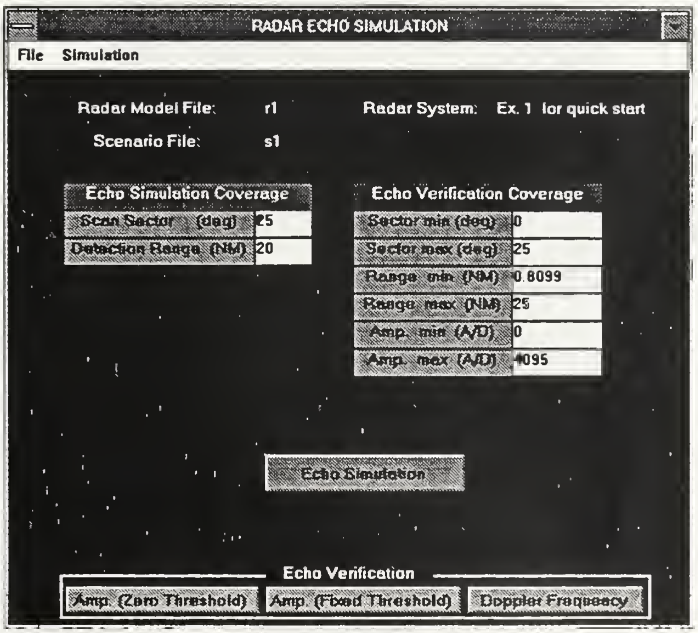


Figure A.24 Radar Echo Verification Functions

Select **Amp. (Zero Threshold)** to verify the amplitude cell-map of the simulated radar echo with zero threshold (Fig. A.25).

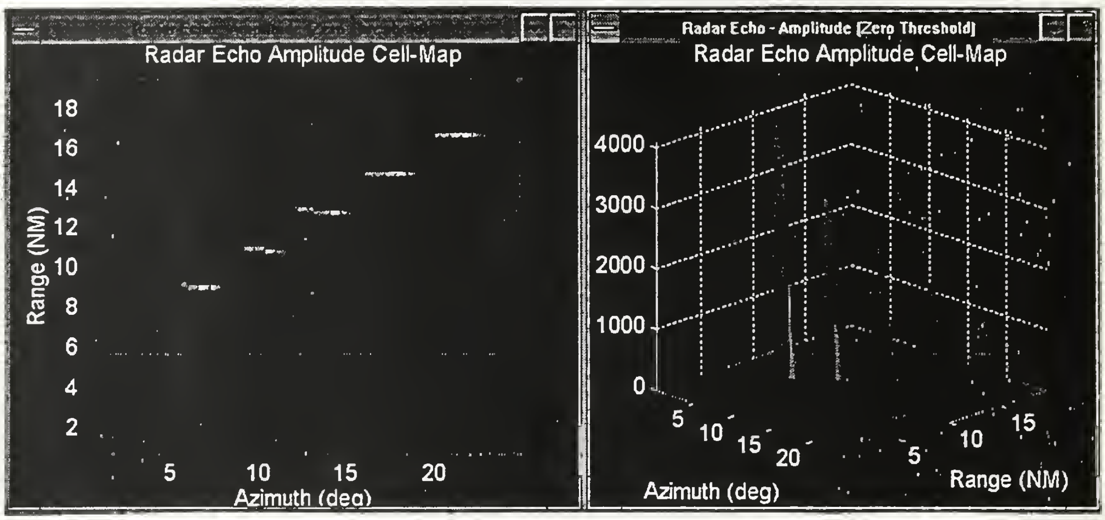


Figure A.25 Amplitude Cell-map with Zero Threshold

Select **Amp. (Fixed Threshold)** to verify the amplitude cell-map of the simulated radar echo with fixed threshold (Fig. A.26).

Select **Doppler Frequency** to verify the Doppler frequency cell-map of the simulated radar echo (Fig . A.27).

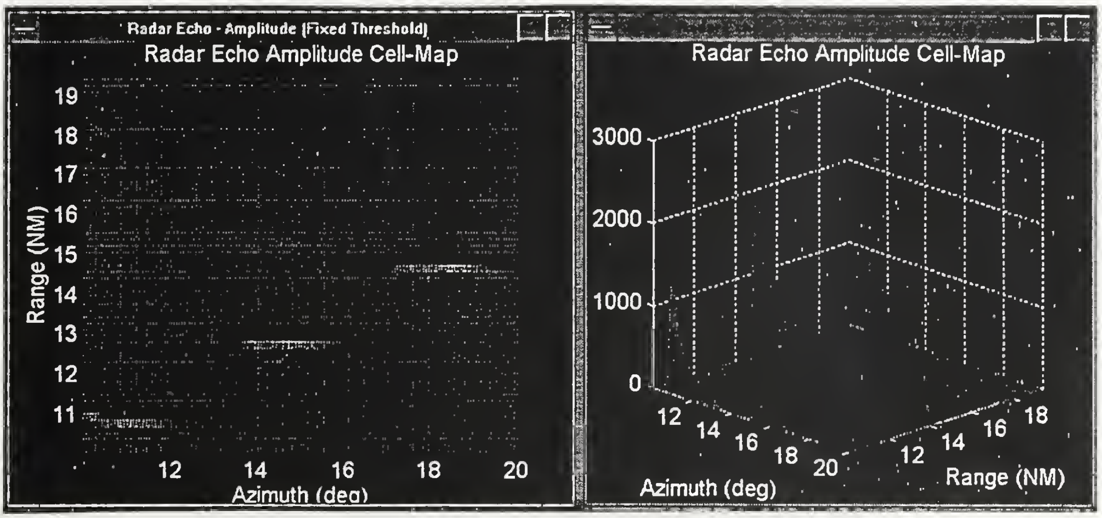


Figure A.26 Amplitude Cell-map with Fixed Threshold

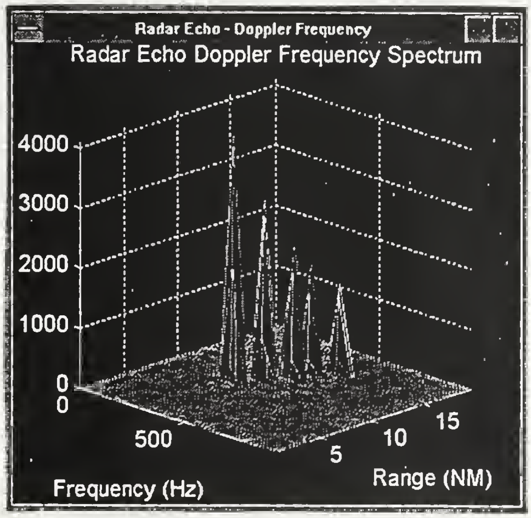


Figure A.27 Doppler Frequency Cell-map

5. Radar Processing Simulation Worksheet

Click the **Processing Simulation** pushbutton from the main menu to open a Radar Processing Simulation worksheet (Fig A.28).

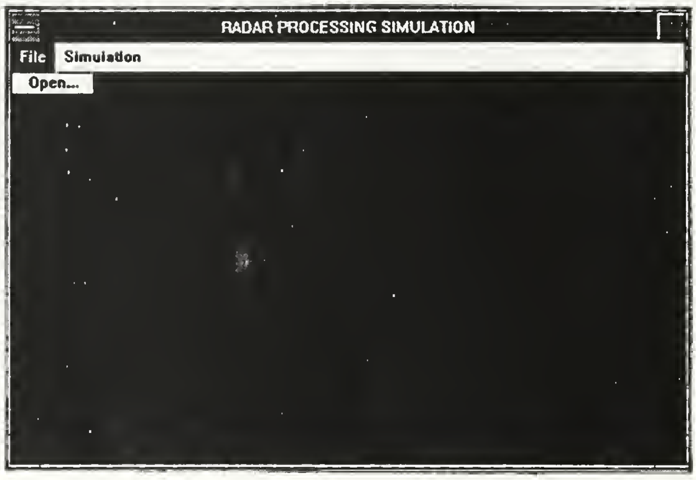


Figure A.28 Radar Processing Simulation Worksheet

a. File

The user can use this function by selecting from the **File** menu bar to open a simulated radar echo file for radar processing simulation.

Select **Open...** to open a simulated radar echo file by entering a desired file name (Fig. A.29).

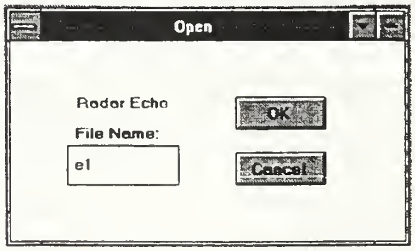


Figure A.29 Open a Simulated Radar Echo File *b. Simulation*

The user can use this function by either selecting from the **Simulation** menu bar or clicking pushbutton on the worksheet to run radar processing and simulation.

Select **Radar Processing** to run the radar processing and produce the amplitude and Doppler cell-map. The user can monitor the processing status from a slider box (Fig. A.30). The simulation functions will be provided when the pre-processing is completed (Fig. A.31).

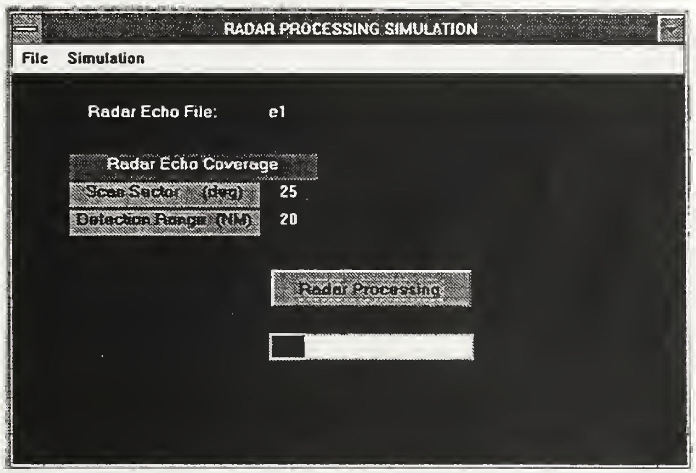


Figure A.30 Radar Processing

Select **Control & Display** to open a simulated PPI display and a SIMULINK simulation control window in order to simulate the radar processing (Fig. A.32). Run the simulation by selecting **Start** from the **Simulation** menu bar on the SIMULINK window. While a simulation is running, the **Start** menu item becomes **Stop**. If the user selects **Stop**, the menu displays **Start** again. The **Clear Trail** pushbutton on the

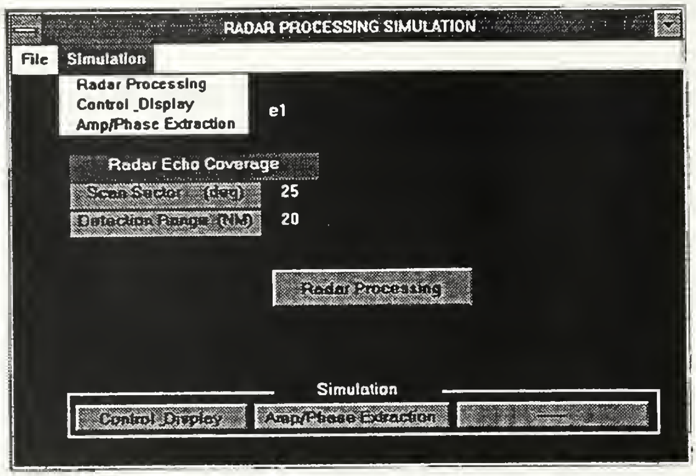


Figure A.31 Radar Processing Simulation Functions

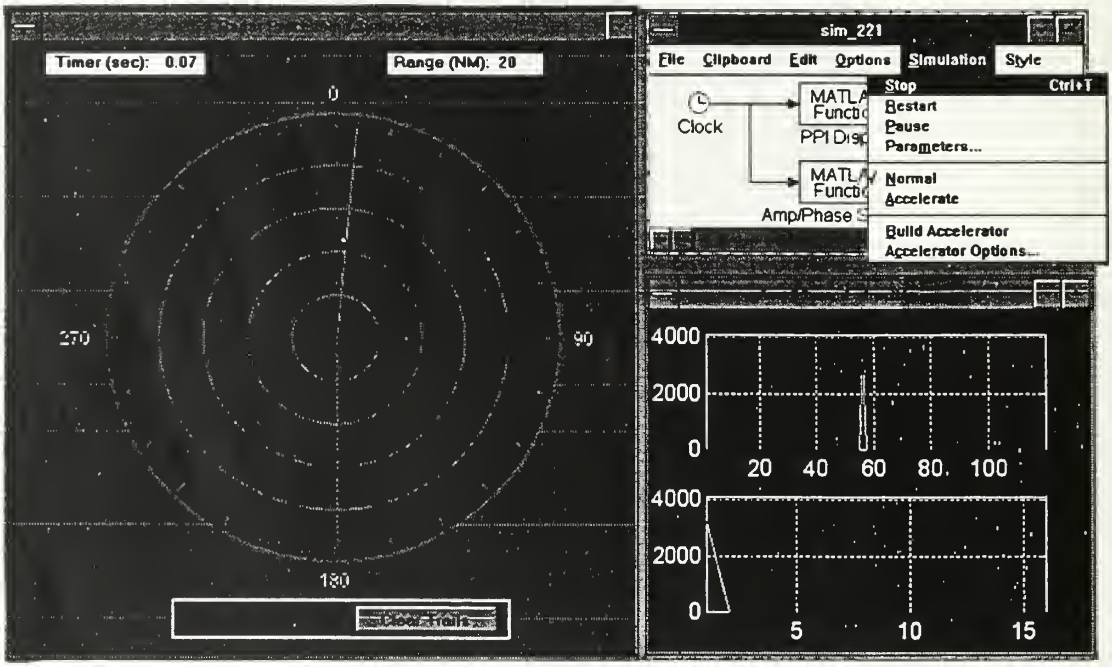


Figure A.32 Control and Display Simulation

PPI displayis used for the PPI screen reset. The simulation time period and step are set by start and stop **Parameters** from the **Simulation** menu bar on the SIMULINK window.

Select **Amp/Phase Extraction** to verify the amplitude and Doppler cell-map produced by processing simulation (Figs. A.33 and A.34).

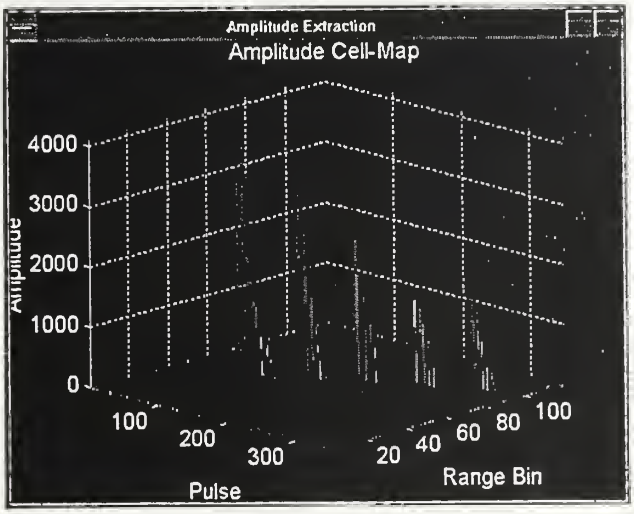


Figure A.33 Amplitude Cell-map Extraction

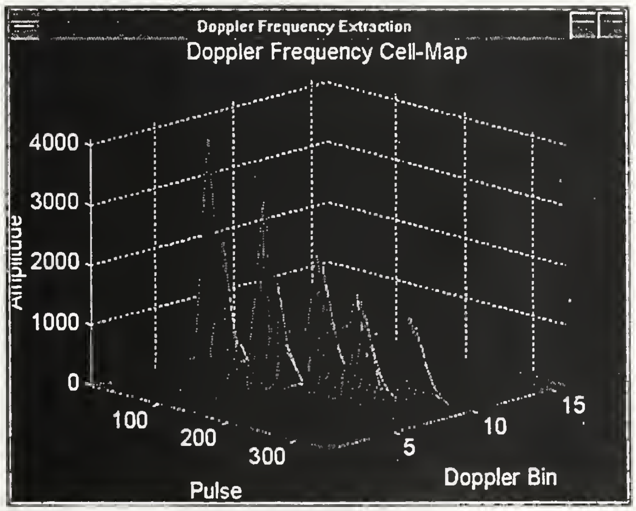


Figure A.34 Doppler Frequency Cell-map Extraction

APPENDIX B. MATLAB COMPUTER PROGRAMS

1. Program Architecture

```
Radar Modeling and Simulation Main Menu              -- rms.m
                        PPI Image                    -- ppi_image.mat

     Search Radar Model Worksheet                    -- model.m
          File          New                          -- mod_11.m
                        Open...                      -- mod_12.m
                        Save                         -- mod_13.m
                        Save As...                   -- mod_14.m
                           Defined Model             -- r1.mat
          Model         Waveform Generation          -- mod_21.m
                        Antenna Pattern              -- mod_22.m
                        System Loss                  -- mod_23.m
                        System Noise                 -- mod_24.m
                        Synchronous Detector         -- mod_25.m
                           (Simulink Model)          -- mod_251.m
                        A/D Converter & STC          -- mod_26.m
                        Doppler Filter & Env.        -- mod_27.m
                        CFAR & Threshold Det.        -- mod_28.m
                        Postdet. Integration         -- mod_29.m

     Scenario Definition Worksheet                   -- scena.m
          File          New                          -- sce_11.m
                        Open...                      -- sce_12.m
                        Save                         -- sce_13.m
                        Save As...                   -- sce_14.m
                           Defined Scenario          -- s1.mat
          Definition    Target Trajectory            -- sce_21.m
                           (Simulink Model)          -- sce_211.m
                           Trajectory Update         -- sce_2111.m
                           Show Trail Control        -- sce_2112.m
                           Clear Trail Control       -- sce_2113.m
                        RCS Fluctuation              -- sce_22.m
                        Jammer Characteristics       -- sce_23.m
                        Clutter Map                  -- sce_24.m
```

Radar Echo Simulation Worksheet			-- enviro.m
	File	Open...	-- env_11.m
		Simulation Coverage	-- env_111.m
		Save As...	-- env_12.m
		Save	-- env_121.m
		Simulated Radar Echo	-- e1.mat
	Simulation	Echo Simulation	-- env_21.m
		AZ Antenna Pattern	-- ant_gaz.m
		EL Antenna Pattern	-- ant_gel.m
		Echo Verification	
		Amp. (Zero Threshold)	-- env_22.m
		Amp. (Fixed Threshold)	-- env_23.m
		Doppler Frequency	-- env_24.m
Radar Processing Simulation Worksheet			-- simula.m
	File	Open...	-- sim_11.m
		Processing Coverage	-- sim_111.m
	Simulation	Radar Processing	-- sim_21.m
		Control & Display	-- sim_22.m
		(Simulink Model)	-- sim_221.m
		PPI Display	-- sim_2211.m
		Amp/Phase Spectrum	-- sim_2212.m
		Clear Trail Control	-- sim_2213.m
		Amp/Phase Extraction	-- sim_23.m

2. M-files Listing

```
% rms
%
% RADAR MODELING & SIMULATION Main Menu
%
%
%  model    [ SEARCH RADAR MODEL            ]
%  scena    [ SCENARIO DEFINITION           ]
%  enviro   [ RADAR ECHO SIMULATION         ]
%  simula   [ RADAR PROCESSING SIMULATION   ]
%

clear;

%------------  create main menu window ---------------------------------------

fig_main=figure('NumberTitle','off','Name','RADAR MODELING & SIMULATION',...
                'MenuBar','none','Resize','off','Position',[200 265 550 445]);

%------------  create menu selection pushbutton ------------------------------

uicontrol(gcf,'Style','pushbutton','Position',[ 30  70 180  40],...
              'String',' Search Radar Model',   'CallBack','model');

uicontrol(gcf,'Style','pushbutton','Position',[ 30  20 180  40],...
              'String','Scenario Definition',   'CallBack','scena');

uicontrol(gcf,'Style','pushbutton','Position',[340  70 180  40],...
              'String','Echo Simulation',       'CallBack','enviro');

uicontrol(gcf,'Style','pushbutton','Position',[340  20 180  40],...
              'String','Processing Simulation', 'CallBack','simula');

%------------  patch a black-white PPI screen --------------------------------

load ppi_image; movie(gcf,pmppi1,1,1,[0 0 0 0]);
clear pmppi1;

%------------  patch 'Radar Modeling & Simulation' logo ----------------------

axis off;
x1=0.2; y1=0.86;
t1='Radar Modeling & Simulation';

  for i=3:13
      st(i)=text(x1,y1,t1);
      set(st(i),'Position',[x1 y1-(i-2)*0.06],'Color',[0 1 0.8],...
                'Rotation',i,'FontSize',i+3,'EraseMode','background');
  end;


end;
```

```
% model
%
% SEARCH RADAR MODEL Worksheet
%
% File    mod_11 | New              |
%             12 | Open...          |
%             13 | Save             |
%             14 | Save as...       |
%
% Model   mod_21 | Waveform Generation            |
%             22 | Antenna Pattern                |
%             23 | System Loss                    |
%             24 | System Noise                   |
%             25 | Synchronous Detector           |
%             26 | A/D Converter                  |
%             27 | Doppler Filter & Envelop Det.  |
%             29 | CFAR & Threshold Detection     |
%             28 | Postdetection Integration      |
%

%------------  create pop-up menu ------------------------------------------

fig_mod=figure('NumberTitle','off','Name','SEARCH RADAR MODEL',...
               'MenuBar','none','Resize','off','Position',[37 127 850 500]);

mod_op1=uimenu(gcf,'Label','File');
        uimenu(mod_op1,'Label','New',...
                                   'CallBack',['file_hndl=1',';','mod_11']);
        uimenu(mod_op1,'Label','Open...',                'CallBack','mod_12');
        uimenu(mod_op1,'Label','Save',                   'CallBack','mod_13');
        uimenu(mod_op1,'Label','Save As...',             'CallBack','mod_14');

mod_op2=uimenu(gcf,'Label','Model');
        uimenu(mod_op2,'Label','Radar Waveform',         'CallBack','mod_21');
        uimenu(mod_op2,'Label','Antenna Pattern,         'CallBack','mod_22');
        uimenu(mod_op2,'Label','System Loss',            'CallBack','mod_23');
        uimenu(mod_op2,'Label','System Noise',           'CallBack','mod_24');
        uimenu(mod_op2,'Label','Synchronous Detector','CallBack','mod_25');
        uimenu(mod_op2,'Label','A/D Converter',          'CallBack','mod_26');
        uimenu(mod_op2,'Label','Doppler Filter & Envelope Det.',...
                                                         'CallBack','mod_27');
        uimenu(mod_op2,'Label','CFAR & Threshold Detection',...
                                                         'CallBack','mod_28');
        uimenu(mod_op2,'Label','Postdet. Integration','CallBack','mod_29');

end;
```

```
% mod_11
%
% SEARCH RADAR MODEL
%                   -- File
%                           -- New
%
%
%  create radar model parameter editable text
%

global pa_A; global pa_B; global pa_C; global pa_D;

%------- editable paramenter no. of each field ------------------------------

No_A=7;       % [Waveform Generation]
No_B=4;       % [Antenna Pattern]
No_C=12;      % [Analog Processor]
No_D=8;       % [A/D, Digital Processor & PPI]

%------- file handle --------------------------------------------------------

if file_hndl == 2           % load data from selected file

   eval(['load d:\matlab\bin\chen\thesis\',pa_file,';']);

else
     pa_file='';            % new
     pa_sys ='';
     pa_A=zeros(1,No_A);
     pa_B=zeros(1,No_B);
     pa_C=zeros(1,No_C);
     pa_D=zeros(1,No_D);
end;


% ------- declare radar paramenter  -----------------------------------------

%  set text strings of field & parameter name

item_file='File Name';
item_sys ='Radar Name';

name_A='Waveform Generation';
item_A(1,:) ='RF Frequency   (MHz)';   item_A(2,:) ='IF Frequency   (MHz)';
item_A(3,:) ='PRF            (KHz)';   item_A(4,:) ='Peak Tx Power   (KW)';
item_A(5,:) ='PW              (us)';   item_A(6,:) ='Recovery Time   (us)';
item_A(7,:) ='Sampling Time   (us)';

name_B= 'Antenna Pattern';
item_B(1,:) ='Mainbeam Pk Gain(dB)';   item_B(2,:) ='-3dB HPBW      (deg)';
item_B(3,:) ='Scan Rate      (RPM)';   item_B(4,:) ='Upspot Angle   (deg)';

name_C='Analog Processor';
item_C(1,:) ='System Loss  Ls (dB)';   item_C(2,:) ='Tx Loss      Lt (dB)';
item_C(3,:) ='Tx Line Loss Lr (dB)';   item_C(4,:) ='System Noise Ts  (K)';
item_C(5,:) ='Ant. Noise Ta    (K)';   item_C(6,:) ='Ant. Noise T`a   (K)';
item_C(7,:) ='Tx Line Noise Tr (K)';   item_C(8,:) ='Rcvr Noise Te    (K)';
item_C(9,:) ='Rcvr Noise Bn  (MHz)';   item_C(10,:)='Rcvr Noise Fn       ';
item_C(11,:)='Prob False Alarm Pfa';   item_C(12,:)='IF Amp. Gain        ';

name_D= 'A/D, Digital Processor & PPI';
item_D(1,:) ='Max Voltage Vmax (V)';   item_D(2,:) ='Min Voltage Vmin (V)';
item_D(3,:) ='A/D Binary Digits   ';   item_D(4,:) ='Doppler Filter No.  ';
```

```
item_D(5,:) ='Az Resolution  (deg)';   item_D(6,:) ='CFAR Det. Window 2n ';
item_D(7,:) ='CFAR Option    (0-3)';   item_D(8,:) ='Display Range   (NM)';


%  set text color for  field name

black =[0    0    0    ]; white  =[1 1    1    ];
red   =[0.75 0    0    ]; green  =[0 0.75 0    ];
yellow=[0.75 0.75 0    ]; lt_blue=[0 0.75 0.75];
gray  =[0.75 0.75 0.75]; blue   =[0 0    0.75];


%  set edit field size

tw=170;              % width for item name
th=23;               % heigh for item name (parameter)
td=25;               % vertical distance between two item (parameter) td > th
aw=50;               % width for parameter


%  establish edit work sheet

tx=50; ty=470;     % initial position for [File Name] (left,top)

uicontrol(gcf,'Style','text','String',item_file,...
              'BackG',blue,'ForeG',white,'Position',[tx ty 115 td]);
uicontrol(gcf,'Style','text','String',pa_file,...
              'BackG',blue,'ForeG',white,'Position',[tx+122 ty 100 td]);


tx=300; ty=470;     % initial position for [Radar Name]

uicontrol(gcf,'Style','text','String',item_sys,...
              'BackG',blue,'ForeG',white,'Position',[tx ty 115 td]);
   ed_pa_sys=uicontrol(gcf,'Style','edit','String',pa_sys,...
              'BackG',white,'Position',[tx+122 ty 150 td],...
              'Callback',['pa_sys=get(ed_pa_sys,''String'');']);


tx=50; ty=400;     % initial position for [Waveform Generation]

uicontrol(gcf,'Style','text','String',name_A,...
              'BackG',lt_blue,'ForeG',white,'Position',[tx ty+td tw+aw+2 th]);
  for i=1:No_A
    uicontrol(gcf,'Style','text','String',item_A(i,:),...
                'BackG',gray, 'Position',[tx ty-(i-1)*td tw th]);

    ed_pa_A(i)=uicontrol(gcf,'Style','edit','String',num2str(pa_A(i)),...
                'BackG',white,'Position',[tx+tw+2 ty-(i-1)*td aw th],...
                'Callback',...
  ['pa_A(',num2str(i),')=str2num(get(ed_pa_A(',num2str(i),'),''String''));']);
  end;


tx=50; ty=180;     % initial position for [Antenna Pattern]

  uicontrol(gcf,'Style','text','String',name_B,...
                'BackG',red,'ForeG',white,'Position',[tx ty+td tw+aw+2 th]);
  for i=1:No_B
    uicontrol(gcf,'Style','text','String',item_B(i,:),...
                  'BackG',gray, 'Position',[tx ty-(i-1)*td tw th]);

    ed_pa_B(i)=uicontrol(gcf,'Style','edit','String',num2str(pa_B(i)),...
```

```
                 'BackG',white,'Position',[tx+tw+2 ty-(i-1)*td aw th],...
                 'Callback',...
  ['pa_B(',num2str(i),')=str2num(get(ed_pa_B(',num2str(i),'),''String''));']);
  end;


tx=300; ty=400;     % initial position for [Analog Processor]

  uicontrol(gcf,'Style','text','String',name_C,...
              'BackG',yellow,'ForeG',white,'Position',[tx ty+td tw+aw+2 th]);
  for i=1:No_C
    uicontrol(gcf,'Style','text','String',item_C(i,:),...
                 'BackG',gray, 'Position',[tx ty-(i-1)*td tw th]);

    ed_pa_C(i)=uicontrol(gcf,'Style','edit','String',num2str(pa_C(i)),...
                 'BackG',white,'Position',[tx+tw+2 ty-(i-1)*td aw th],...
                 'Callback',...
  ['pa_C(',num2str(i),')=str2num(get(ed_pa_C(',num2str(i),'),''String''));']);
  end;


tx=550; ty=400;     % initial position for [A/D, Digital Processor & PPI]

  uicontrol(gcf,'Style','text','String',name_D,...
               'BackG',green,'ForeG',white,'Position',[tx ty+td tw+aw+2 th]);
  for i=1:No_D
    uicontrol(gcf,'Style','text','String',item_D(i,:),...
                 'BackG',gray, 'Position',[tx ty-(i-1)*td tw th]);

    ed_pa_D(i)=uicontrol(gcf,'Style','edit','String',num2str(pa_D(i)),...
                 'BackG',white,'Position',[tx+tw+2 ty-(i-1)*td aw th],...
                 'Callback',...
  ['pa_D(',num2str(i),')=str2num(get(ed_pa_D(',num2str(i),'),''String''));']);
  end;



%------------  create Model selection pushbutton ------------------------------

uicontrol(gcf,'Style','text','Position',[  46   5 540 70],'BackG',white);
uicontrol(gcf,'Style','text','Position',[  48   7 536 66],'BackG',black);
uicontrol(gcf,'Style','text','Position',[ 260 60 100 25],...
              'String','Model','BackG',black,'ForeG',white);


uicontrol(gcf,'Style','pushbutton','Position',[ 55 40 100 25],...
              'String','Waveform',    'CallBack','mod_21');

uicontrol(gcf,'Style','pushbutton','Position',[160 40 100 25],...
              'String','Ant. Pattern', 'CallBack','mod_22');

uicontrol(gcf,'Style','pushbutton','Position',[265 40 100 25],...
              'String','Sys. Loss',     'CallBack','mod_23');

uicontrol(gcf,'Style','pushbutton','Position',[370 40 100 25],...
              'String','Sys. Noise',    'CallBack','mod_24');

uicontrol(gcf,'Style','pushbutton','Position',[475 40 100 25],...
              'String','Sync. Det.',    'CallBack','mod_25');

uicontrol(gcf,'Style','pushbutton','Position',[ 55 10 100 25],...
              'String','A/D',           'CallBack','mod_26');
```

```
uicontrol(gcf,'Style','pushbutton','Position',[160 10 100 25],...
              'String','Doppler & Env','CallBack','mod_27');

uicontrol(gcf,'Style','pushbutton','Position',[265 10 100 25],...
              'String','CFAR',         'CallBack','mod_28');

uicontrol(gcf,'Style','pushbutton','Position',[370 10 100 25],...
              'String','PDI',          'CallBack','mod_29');

uicontrol(gcf,'Style','pushbutton','Position',[475 10 100 25],...
              'String','----',         'CallBack','');

end;
```

```
% mod_12
%
% SEARCH RADAR MODEL
%                       -- File
%                               -- Open...
%
%
%

%-----------  create file open window -----------------------------------

pa_file='';
fig_open=figure('NumberTitle','off','Name','Open','Color',[1 1 1],...
                'MenuBar','none','Position',[280 200 350 180]);

 uicontrol(gcf,'Style','text','String','Radar Model',...
                'BackG',[1 1 1],'ForeG',[0 0 1],'Position',[25 100 150 30]);
 uicontrol(gcf,'Style','text','String','File Name:',...
                'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[45  75 100 30]);
 uicontrol(gcf,'Style','text','String','',...
                'BackG',[0 0 0],'Position',[50  50 100 36]);
 uicontrol(gcf,'Style','text','String','',...
                'BackG',[1 1 1],'Position',[51  51  98 34]);
 ed_pa_file=uicontrol(gcf,'Style','edit','String',pa_file,...
                'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[56 51 90 26],...
                'Callback',['pa_file=get(ed_pa_file,''String'');']);

%-----------  create file selection pushbutton --------------------------

uicontrol(gcf,'Style','pushbutton','Position',[200 100  80  30],...
              'String','OK',...
            'CallBack',['delete(fig_open)',';','file_hndl=2',';','mod_11']);

uicontrol(gcf,'Style','pushbutton','Position',[200 50  80  30],...
              'String','Cancel','CallBack','delete(fig_open);');

end;
```

```
% mod_13
%
% SEARCH RADAR MODEL
%                       -- File
%                               -- Save
%
%

eval(['save d:\matlab\bin\chen\thesis\',pa_file,...
                                       ' pa_file pa_sys pa_A pa_B pa_C pa_D;']);


end;
```

```
% mod_14
%
% SEARCH RADAR MODEL
%                    -- File
%                            -- Save As...
%
%

%------------  create file Save As window ------------------------------------

fig_save_as=figure('NumberTitle','off','Name','Save As','Color',[1 1 1],...
                'MenuBar','none','Position',[300 200 350 180]);

 uicontrol(gcf,'Style','text','String','Radar Model',...
                'BackG',[1 1 1],'ForeG',[0 0 1],'Position',[25 100 150 30]);
 uicontrol(gcf,'Style','text','String','File Name:',...
                'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[45  75 100 30]);
 uicontrol(gcf,'Style','text','String','',...
               'BackG',[0 0 0],'Position',[50  50 100 36]);
 uicontrol(gcf,'Style','text','String','',...
               'BackG',[1 1 1],'Position',[51  51  98 34]);
 ed_pa_file=uicontrol(gcf,'Style','edit','String',pa_file,...
               'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[56 51 90 26],...
               'Callback',['pa_file=get(ed_pa_file,''String'');']);

%------------  create file selection pushbutton ------------------------------

uicontrol(gcf,'Style','pushbutton','Position',[200 100  80  30],...
         'String','Save', 'CallBack',['delete(fig_save_as)',';','mod_13']);

uicontrol(gcf,'Style','pushbutton','Position',[200 50  80  30],...
         'String','Cancel','CallBack','delete(fig_save_as);');

end;
```

```
function mod_21
%
% mod_21
%
% SEARCH RADAR MODEL
%                    -- Model
%                            -- Waveform Generation
%
%

end;
```

```
function mod_22
%
% mod_22
%
% SEARCH RADAR MODEL
%                    -- Model
%                            -- Antenna Pattern
%
%
%  Display Azimuth & Elevation Antenna Pattern
%
%
%  Azimuth:   -180 ~ 179, digitized per degree, unit -dB
%  Elevation:  -20 ~  39, digitized per degree, unit -dB
%

AntAZ=...
[37.5 37.7 38.0 38.5 39.0 38.7 37.5 36.0 35.5 36.0 38.6 40.0 40.2 39.0 37.8
 38.5 40.0 43.5 42.4 41.1 42.5 47.0 50.5 49.0 45.0 43.0 42.0 42.2 41.5 40.0
 37.0 35.8 37.0 39.0 42.5 41.5 40.5 41.0 42.0 44.0 45.2 44.0 41.0 40.0 41.0
 44.2 44.0 42.0 40.0 39.0 39.0 40.0 44.0 49.0 47.0 44.2 43.8 44.2 45.5 45.6
 45.5 45.4 45.2 43.2 41.0 39.0 38.4 38.6 39.0 38.7 37.5 36.0 35.0 34.2 33.5
 33.0 33.4 34.2 35.9 36.3 35.5 33.5 32.0 31.0 30.8 31.1 31.5 32.5 33.5 34.7
 35.0 34.5 33.0 32.0 31.8 32.0 34.0 36.2 38.0 40.0 39.0 37.5 36.2 35.2 34.0
 35.0 36.2 37.4 37.0 36.0 35.8 36.2 37.2 37.2 36.1 34.8 34.2 35.2 36.8 39.1
 40.5 40.5 40.0 39.9 40.0 39.9 39.7 39.5 39.7 40.0 39.0 37.0 35.5 35.5 37.0
 39.5 39.9 38.5 37.0 36.2 37.5 45.5 53.0 51.0 50.0 46.0 41.0 39.0 38.0 37.5
 38.5 42.0 40.8 44.0 52.0 46.0 39.8 39.2 38.7 40.0 50.6 42.2 47.8 40.0 35.0
 32.9 37.7 42.7 37.0 32.0 28.8 30.0 50.0 35.0 32.0 27.3 17.3  9.6  4.2  1.0
  0.0  1.0  4.2  9.6 17.3 27.3 30.5 30.0 48.0 40.0 33.0 44.0 42.0 49.0 40.0
 34.2 38.0 47.0 43.5 55.0 45.0 39.2 43.0 46.2 43.5 51.2 45.0 39.8 41.0 41.2
 40.0 39.0 38.0 37.8 38.0 40.0 41.0 42.8 43.5 40.0 38.0 36.2 38.0 39.0 41.0
 40.0 37.6 35.0 34.0 35.0 37.0 39.2 38.5 37.8 37.6 38.5 39.5 41.0 42.0 41.0
 40.0 38.0 36.2 35.0 34.7 34.9 35.0 35.0 35.5 35.7 35.5 35.4 35.2 35.0 34.7
 34.3 34.0 34.2 34.6 35.5 37.0 38.5 38.0 36.0 33.8 32.0 31.3 31.4 31.6 31.9
 32.0 31.8 31.5 31.2 30.9 30.7 30.8 31.0 31.5 31.8 32.0 32.5 33.0 34.0 34.5
 34.4 33.7 33.0 33.4 34.1 35.0 35.8 36.6 38.0 40.0 41.4 41.8 41.3 41.0 42.0
 46.0 47.9 47.7 46.9 46.1 46.3 49.0 55.0 50.0 43.0 40.0 39.2 40.0 43.2 46.5
 54.5 52.0 46.0 42.0 41.0 40.0 39.0 38.0 37.0 36.8 37.0 38.0 38.6 37.2 35.0
 34.8 36.0 40.0 42.0 41.4 41.2 41.7 42.6 42.8 42.0 40.0 39.6 41.0 43.0 44.0
 40.0 38.9 38.7 40.0 42.8 43.2 41.0 39.2 38.3 38.0 38.5 38.7 38.4 38.0 37.9];

AntG=-AntAZ';  G=AntG(:);  Gn=60+G;

fig_ant1=figure('NumberTitle','off','Name','Antenna Azimuth Pattern (1)',...
                   'MenuBar','none','Position',[ 15 420 525 255]);

t=-180:1:179;
plot(t,G); grid;
axis([-180 180 -60 0]);
xlabel('Azimuth Angle (deg)'); ylabel('Relative Gain (dB)');


fig_ant2=figure('NumberTitle','off','Name','Antenna Azimuth Pattern (2)',...
                 'MenuBar','none','Position',[550 420 440 255]);

hold on;

%
%   Creat polar plot
%

disp_rad=60;     d_mk=20;
```

```
white=[1 1 1];
yellow=[1 1 0];

Rg=disp_rad;
ang0=0:pi/180:2*pi;
px=Rg*cos(ang0); py=Rg*sin(ang0);
plot(px,py,'Color',white,'LineWidth',1);          % outer ring

L1=[0 disp_rad];                                  % azimuth marker
ang1=pi/180*30:pi/180*30:2*pi;                    % every 30 deg
rx=L1'*cos(ang1); ry=L1'*sin(ang1);
plot(rx,ry,'Color',white,'LineWidth',1,'LineStyle',':');


text(-4,67,'90','FontSize',12);                   % azimuth marker
text(65,0,'0','FontSize',12);                     % 0,90,180,270 deg
text(-11,-67,'270','FontSize',12);
text(-84,0,'180','FontSize',12);

ang0=0:pi/180:2*pi;                               % range marker
L0=[20 40];
px=cos(ang0)'*L0; py=sin(ang0)'*L0;
plot(px,py,'Color',white,'LineWidth',1,'LineStyle',':');

lx=disp_rad;  ly=disp_rad;
axis([-lx lx -ly ly]);
axis('equal');
axis('off');

t=-pi:pi/180:pi-pi/180;
sx=Gn'.*cos(t);
sy=Gn'.*sin(t);
plot(sx,sy,'Color',yellow,'LineWidth',1);

hold off;



AntEL=[30.0 30.0 30.0 30.0 30.0 30.0 30.0 27.5 22.0 19.0
       15.5 13.0 11.0  8.5  7.0  5.5  4.0  3.0  2.0  1.4
        0.8  0.4  0.1  0.0  0.1  0.4  0.9  1.7  2.3  3.3
        4.8  5.8  6.9  7.5  8.2  8.4  8.8  9.3 10.0 10.4
       11.0 11.9 12.5 13.0 13.5 14.0 14.6 15.2 16.0 17.2
       19.1 20.7 22.0 23.0 23.8 24.6 26.0 27.1 28.7 30.0];

AntG=-AntEL';  G=AntG(:);  Gn=2*(30+G);

fig_ant1=figure('NumberTitle','off','Name','Antenna Elevation Pattern (1)',...
                 'MenuBar','none','Position',[ 15 120 525 255]);

t=-20:1:39;
plot(t,G); grid;
axis([-20 40 -30 0]);
xlabel('Elevation Angle (deg)'); ylabel('Relative Gain (dB)');


fig_ant2=figure('NumberTitle','off','Name','Antenna Elevation Pattern (2)',...
                'MenuBar','none','Position',[550 120 440 255]);

hold on;

%
%   Creat polar plot
```

```
%

disp_rad=60;     d_mk=20;
white=[1 1 1];
yellow=[1 1 0];

Rg=disp_rad;
ang0=0:pi/180:2*pi;
px=Rg*cos(ang0); py=Rg*sin(ang0);
plot(px,py,'Color',white,'LineWidth',1);          % outer ring

L1=[0 disp_rad];                                   % azimuth marker
ang1=pi/180*30:pi/180*30:2*pi;                     % every 30 deg
rx=L1'*cos(ang1); ry=L1'*sin(ang1);
plot(rx,ry,'Color',white,'LineWidth',1,'LineStyle',':');


text(-4,67,'90','FontSize',12);                   % azimuth marker
text(65,0,'0','FontSize',12);                     % 0,90,180,270 deg
text(-11,-67,'270','FontSize',12);
text(-84,0,'180','FontSize',12);

ang0=0:pi/180:2*pi;                               % range marker
L0=[20 40];
px=cos(ang0)'*L0; py=sin(ang0)'*L0;
plot(px,py,'Color',white,'LineWidth',1,'LineStyle',':');

lx=disp_rad;  ly=disp_rad;
axis([-lx lx -ly ly]);
axis('equal');
axis('off');

t=-20:1:39;
sx=Gn'.*cos(t*pi/180);
sy=Gn'.*sin(t*pi/180);
plot(sx,sy,'Color',yellow,'LineWidth',1);

hold off;

end;
```

```
function mod_23
%
% mod_23
%
% SEARCH RADAR MODEL
%                    -- Model
%                            -- System Loss
%
%

end;
```

```
function mod_24
%
% mod_24
%
% SEARCH RADAR MODEL
%                    -- Model
%                            -- System Noise
%
%
%  Display System Thermal Random Noise Model
%

global pa_C;

     Fn=pa_C(10);
     Pfa=pa_C(11);
     Bn=pa_C(9)*1e6;      % Hz <--- MHz

     k_Boltz=1.38e-23;
     T0=290;
     P_noise=k_Boltz*T0*Bn*Fn;
     V_noise=sqrt(P_noise/2);

     V_thresh=sqrt(-2*log(Pfa))*V_noise;

%
% Rayleigh random variable -- sqrt[N(0,var)^2+N(0,var)^2]
%

var=P_noise;
std=V_noise;                           % Noise alone

for i=1:100
  Vn_I=std*randn(1,100);
  Vn_Q=std*randn(1,100);
  Vn(i,:)=sqrt(Vn_I.*Vn_I+Vn_Q.*Vn_Q);
  Vnt(i,:)=Vn(i,:);
   for j=1:100
      if Vnt(i,j) < V_thresh
        Vnt(i,j)=V_thresh;
      end
   end

end


fig_ns1=figure('NumberTitle','off','Name','System Thermal Noise',...
               'MenuBar','none','Position',[ 15 60 525 285]);

figure(fig_ns1);
%meshz(Vnt);
 meshz(Vn);
grid;  axis([1 100 1 100 0 max(max(Vn))]);
xlabel('Range cell');  ylabel('Pulse No.'); zlabel('Amplitude (Volt)');


%
% Random Noise Probability Density Function
%

sn=100;                               % n samples for PDF estimation

fig_ns2=figure('NumberTitle','off','Name',...
```

```
                'Noise Probability Density Function',...
                'MenuBar','none','Position',[550 60 440 285]);

figure(fig_ns2);
Vn1=Vn(:);              % transfer matrix to vector
[n,x]=hist(Vn1,sn);
bar(x,n/10000); grid; axis([0 max(Vn1) 0 max(n)/10000]);
xlabel('Noise Amplitude (Volt)');  ylabel('Probability');
hold on;
plot([V_thresh V_thresh],[0 max(n)/10000],'r');
hold off;


end;




% mod_25
%
% SEARCH RADAR MODEL
%                    -- Model
%                            -- Synchronous Detector
%
%
%  Run Synchronous Detector Model by simulink
%

mod_251;    % simulink simulation model

end;





function mod_26
%
% mod_26
%
% SEARCH RADAR MODEL
%                    -- Model
%                            -- A/D Converter
%
%

end;





function mod_27
%
% mod_27
%
% SEARCH RADAR MODEL
%                    -- Model
%                            -- Doppler Filter & Envelope Detector
%
%

end;
```

```
function mod_28
%
% mod_28
%
% SEARCH RADAR MODEL
%                     -- Model
%                             -- CFAR & Threshold Detection
%
%
%  Display CFAR & Threshold Detection Model
%

global pa_C; global pa_D;

%
% CFAR Constant Detector Scale Factor Table
%
% matrix index column: 2n=8,16,24,32
%              row:    Pfa=1e-4,1e-6,1e-8
%

  TCA_table=[ 2.162 0.778 0.468 0.334;
              4.623 1.371 0.778 0.54;
              9.0   2.162 1.154 0.778 ];
  TGO_table=[ 3.6   1.36  0.833 0.602;
              7.78  2.42  1.4   0.983;
             15.3   3.84  2.092 1.425 ];
  TSO_table=[10.88  2.444 1.277 0.851;
             36.0   5.131 0.54  1.475;
            117.9   9.905 3.916 2.302 ];
%

     Fn=pa_C(10);
     Pfa=pa_C(11);
     Bn=pa_C(9)*1e6;        % Hz <--- MHz
     CFAR2n=pa_D(6);

     k_Boltz=1.38e-23;
     T0=290;
     P_noise=k_Boltz*T0*Bn*Fn;
     V_noise=sqrt(P_noise/2);


     T_fixed=sqrt(-2*log(Pfa));

     col=-log10(Pfa)/2-1;
     row=CFAR2n/8;

%    T_CA=(Pfa)^(-1/CFAR2n)-1;
     T_CA=TCA_table(col,row);
     T_GO=TGO_table(col,row);
     T_SO=TSO_table(col,row);


     VT_thresh=T_fixed*V_noise;


     V_sig1=0.9*VT_thresh;
     V_sig2=1.6*VT_thresh;

%
% Gaussian signal envelope
%
```

```
Vs=zeros(1,100);

dx=-10:10; dx2=dx.*dx/2;
Vs(20:40)=V_sig1*exp(-dx2);
Vs(60:80)=V_sig2*exp(-dx2);

fig_s=figure('NumberTitle','off','Name',...
             'Signal with Fixed Threshold',...
             'MenuBar','none','Position',[525 60 480 285]);

figure(fig_s);
for i=1:100
  line([i i],[Vs(i) 0]);
end;
grid;  axis([1 100 0 max(Vs)]);
xlabel('Azimuth cell'); ylabel('Amplitude (Voltage)');


V_T=ones(1,100)*VT_thresh;
x=1:100;

hold on;
plot(x,V_T,'r')
hold off;

%
% Rayleigh random noise
%

Nvar=P_noise;
Nstd=V_noise;

for i=1:100
  Vn_I=Nstd*randn(1,100);
  Vn_Q=Nstd*randn(1,100);
  Vn(i,:)=sqrt(Vn_I.*Vn_I+Vn_Q.*Vn_Q);
end


fig_ns1=figure('NumberTitle','off','Name',...
               'Signal+Noise with CFAR Threshold',...
               'MenuBar','none','Position', [18 60 480 285]);

figure(fig_ns1);

Vn(1,1:100)=Vn(1,1:100)+Vs(1:100);
for i=1:100
  line([i i],[Vn(1,i) 0]);
end;
grid;  axis([1 100 0 2.0*max(Vn(1,1:100))]);
xlabel('Azimuth cell'); ylabel('Amplitude (Voltage)');



% Cell Averaging CA-CFAR processing

dN=CFAR2n/2;

V_CA=ones(1,100)*VT_thresh;
V_GO=ones(1,100)*VT_thresh;
V_SO=ones(1,100)*VT_thresh;

for i=1+(dN+1):100-(dN+1)
```

```
  ZL=sum(Vn(1,i-(dN+1):i-2));          % leave 1 guard cell
  ZR=sum(Vn(1,i+2:i+dN+1));            % leave 1 guard cell
  V_CA(i)=T_CA*(ZL+ZR)/CFAR2n;
  V_GO(i)=T_GO*max(ZL,ZR)/dN;
  V_SO(i)=T_SO*min(ZL,ZR)/dN;
end;

hold on;
x=1:100;
plot(x,V_CA,'r');
plot(x,V_GO,'g');
plot(x,V_SO);
hold off;

end;
```

```
function mod_29
%
% mod_29
%
% SEARCH RADAR MODEL
%                    -- Model
%                            -- Postdetection Integration
%
%

end;
```

```
% scena
%
% SCENARIO DEFINITION Worksheet
%
% File         sce_11 | New              |
%                  12 | Open...          |
%                  13 | Save             |
%                  14 | Save as...       |
%
% Definition   sce_21 | Target Trajectory       |
%                  22 | Target RCS Fluctuation  |
%                  23 | Jammer Characteristics  |
%                  24 | Clutter Map             |
%

%------------  create pop-up menu -------------------------------------------

fig_sce=figure('NumberTitle','off','Name','SCENARIO DEFINITION',...
               'MenuBar','none','Resize','off','Position', [74 50 550 600]);

sce_op1=uimenu(gcf,'Label','File');
        uimenu(sce_op1,'Label','New',...
                                     'CallBack',['file_hndl=1',';','sce_11']);
        uimenu(sce_op1,'Label','Open...',                  'CallBack','sce_12');
        uimenu(sce_op1,'Label','Save',                     'CallBack','sce_13');
        uimenu(sce_op1,'Label','Save As...',               'CallBack','sce_14');

sce_op2=uimenu(gcf,'Label','Definition');
        uimenu(sce_op2,'Label','Target Trajectory',     'CallBack','sce_21');
        uimenu(sce_op2,'Label','Target RCS Fluctuation','CallBack','sce_22');
        uimenu(sce_op2,'Label','Jammer Characteristics','CallBack','sce_23');
        uimenu(sce_op2,'Label','Clutter Map',           'CallBack','sce_24');

end;
```

```
% sce_11
%
% SEENARIO DEFINITION
%                  -- File
%                         -- New
%
%
%  create scenario parameter editable text
%

global pa_T;

%------- editable parameter no. of each field -----------------------

No_tgt =5;
No_item=15;

%------- file handle ------------------------------------------------

if file_hndl == 2                  % load data from selected file

   eval(['load d:\matlab\bin\chen\thesis\',pa_file,';']);

else
     pa_file='';                   % new
     pa_T=zeros(No_item,No_tgt);

end;


% ------- declare scenario parameter  ------------------------------

%  set text strings of field & parameter name

item_file='File Name';

item_no=     ' Item      \      No.';
item_T( 1,:)='Slant Range    (NM)';
item_T( 2,:)='Azimuth       (deg)';
item_T( 3,:)='Altitude       (ft)';
item_T( 4,:)='Heading       (deg)';
item_T( 5,:)='Velocity    (Knots)';
item_T( 6,:)='Average RCS   (m^2)';
item_T( 7,:)='RCS Fluctuate (0-4)';
item_T( 8,:)='Jammer Type   (0-2)';
item_T( 9,:)='Peak Tx Power  (Kw)';
item_T(10,:)='Ant. Gain      (dB)';
item_T(11,:)='Bandwidth     (MHz)';
item_T(12,:)='PRF           (KHz)';
item_T(13,:)='Loss           (dB)';
item_T(14,:)='ON  Time      (sec)';
item_T(15,:)='OFF Time      (sec)';


%  set text color for  field name

black =[0    0    0   ]; white  =[1 1    1   ];
red   =[0.75 0    0   ]; green  =[0 0.75 0   ];
yellow=[0.75 0.75 0   ]; lt_blue=[0 0.75 0.75];
gray  =[0.75 0.75 0.75]; blue   =[0 0    0.75];


%  set edit field size
```

```
tw=170;              % width for item name
th=23;               % heigh for item name (parameter)
td=25;               % vertical distance between two item (parameter) td > th
aw=48;               % width for parameter
pd=50;               % horizontal distance between two parameter pd > aw


%  establish edit worksheet

tx=50; ty=550;       % initial position for File Name (left,top)

uicontrol(gcf,'Style','text','String',item_file,...
              'BackG',blue,'ForeG',white,'Position',[tx ty 115 td]);
uicontrol(gcf,'Style','text','String',pa_file,...
              'BackG',blue,'ForeG',white,'Position',[tx+122 ty 100 td]);

tx=50; ty=520;       % initial position for Item \ No.

 uicontrol(gcf,'Style','text','String',item_no,...
               'BackG',lt_blue,'ForeG',white,'Position',[tx ty tw th]);

% red enhancement for jammer

 uicontrol(gcf,'Style','text',...
               'BackG',red, 'Position',[tx ty-td*No_item tw+pd*No_tgt td*8]);


 for j=1:No_tgt
   uicontrol(gcf,'Style','text','String',num2str(j),...
       'BackG',lt_blue,'ForeG',white,'Position',[tx+tw+2+pd*(j-1) ty aw th]);
 end;

 for i=1:No_item
      uicontrol(gcf,'Style','text','String',item_T(i,:),...
                     'BackG',gray, 'Position',[tx ty-td*i tw th]);
 end;

 for i=1:No_item
   for j=1:No_tgt
   ed_pa_T(i,j)=uicontrol(gcf,'Style','edit','String',num2str(pa_T(i,j)),...
               'BackG',white,'Position',[tx+tw+2+pd*(j-1) ty-td*i aw th],...
               'Callback',...
             ['pa_T(',num2str(i),',',num2str(j),')=str2num(get(ed_pa_T(',...
                       num2str(i),',',num2str(j),'),''String''));']);
   end;
 end;


%------------  create definition selection pushbutton -----------------------

uicontrol(gcf,'Style','text','Position',[  20 25 520 40],'BackG',white);
uicontrol(gcf,'Style','text','Position',[  22 27 516 36],'BackG',black);
uicontrol(gcf,'Style','text','Position',[ 230 50 100 25],...
              'String','Definition','BackG',black,'ForeG',white);


uicontrol(gcf,'Style','pushbutton','Position',[ 30 30 140 25],...
              'String','Target Trajectory','CallBack','sce_21');

uicontrol(gcf,'Style','pushbutton','Position',[175 30 120 25],...
              'String','RCS Fluctuation',  'CallBack','sce_22');

uicontrol(gcf,'Style','pushbutton','Position',[300 30 120 25],...
```

```
            'String','Jammer Char.',      'CallBack','sce_23');

uicontrol(gcf,'Style','pushbutton','Position',[425 30 100 25],...
            'String','Clutter Map',       'CallBack','sce_24');


end;






% sce_12
%
% SCENARIO DEFINITION
%                   -- File
%                           -- Open...
%
%

%------------  create file open window --------------------------------------

pa_file='';
fig_open=figure('NumberTitle','off','Name','Open','Color',[1 1 1],...
                'MenuBar','none','Position',[300 200 350 180]);

uicontrol(gcf,'Style','text','String','Scenario',...
            'BackG',[1 1 1],'ForeG',[0.75 0 0],'Position',[45 100 100 30]);
uicontrol(gcf,'Style','text','String','File Name:',...
            'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[45  75 100 30]);
uicontrol(gcf,'Style','text','String','',...
            'BackG',[0 0 0],'Position',[50  50 100 36]);
uicontrol(gcf,'Style','text','String','',...
            'BackG',[1 1 1],'Position',[51  51  98 34]);
ed_pa_file=uicontrol(gcf,'Style','edit','String',pa_file,...
            'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[56 51 90 26],...
            'Callback',['pa_file=get(ed_pa_file,''String'');']);

%------------  create file selection pushbutton ---------------------------

uicontrol(gcf,'Style','pushbutton','Position',[200 100  80  30],...
            'String','OK',...
            'CallBack',['delete(fig_open)',';','file_hndl=2',';','sce_11']);

uicontrol(gcf,'Style','pushbutton','Position',[200 50  80  30],...
            'String','Cancel','CallBack','delete(fig_open);');

end;
```

```
% sce_13
%
% SCENARIO DEFINITION
%                   -- File
%                           -- Save
%
%

eval(['save d:\matlab\bin\chen\thesis\',pa_file,' pa_file pa_T;']);


end;
```

```
% sce_14
%
% SCENARIO DEFINITION
%                   -- File
%                           -- Save As...
%
%

%------------  create file Save As window ------------------------------------

fig_save_as=figure('NumberTitle','off','Name','Save As','Color',[1 1 1],...
                'MenuBar','none','Position',[300 200 350 180]);

uicontrol(gcf,'Style','text','String','Scenario',...
              'BackG',[1 1 1],'ForeG',[0.75 0 0],'Position',[45 100 100 30]);
uicontrol(gcf,'Style','text','String','File Name:',...
              'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[45  75 100 30]);
uicontrol(gcf,'Style','text','String','',...
              'BackG',[0 0 0],'Position',[50  50 100 36]);
uicontrol(gcf,'Style','text','String','',...
              'BackG',[1 1 1],'Position',[51  51  98 34]);
ed_pa_file=uicontrol(gcf,'Style','edit','String',pa_file,...
              'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[56 51 90 26],...
              'Callback',['pa_file=get(ed_pa_file,''String'');']);

%------------  create file selection pushbutton ------------------------------

uicontrol(gcf,'Style','pushbutton','Position',[200 100  80  30],...
          'String','Save', 'CallBack',['delete(fig_save_as)',';','sce_13']);

uicontrol(gcf,'Style','pushbutton','Position',[200 50  80  30],...
              'String','Cancel','CallBack','delete(fig_save_as);');

end;
```

```
% sce_21
%
% SEENARIO DEFINITION
%                    -- Definition
%                            -- Target Trajectory
%
%
%
%  Display Target Trajectory Model
%

global T_Range; global T_Az; global T_Alt; global T_Speed; global T_Head;
global J_type; global J_on; global J_off;
global tgt_color; global on_flag;
global Scan_rate; global tgt_no; global disp_dr;
global hndl_tgt; global hndl_sl; global hndl_clk;


deg2rad=pi/180;  rad2deg=180/pi;

%--- get radar model parameter --------------------------

     prf       = pa_A(3)*1e3;          % Hz   <-- KHz
     Scan_rate = pa_B(3)*6;            % deg/sec <-- RPM
     Rdisp     = pa_D(8)*1.852e3;      % m    <-- Nm
     Rmax      = Rdisp;
     Rmin      = pa_D(2)*1.852e3;      % m    <-- NM

%--- get scenario parameter -----------------------------

  tgt_no=0;

  for i=1:No_tgt
     if pa_T(1,i) ~= 0
       tgt_no=tgt_no+1;
       T_Range(tgt_no)  = pa_T(1,i)*1.852e3;       % m <-- NM
       T_Az(tgt_no)     = pa_T(2,i);               % deg
       T_Alt(tgt_no)    = pa_T(3,i)*0.3048;        % m      <-- ft
       T_Speed(tgt_no)  = pa_T(4,i)*1.852e3/3600;  % m/sec <-- Knots
       T_Head(tgt_no)   = pa_T(5,i);               % deg

       J_type(tgt_no)   = pa_T(8,i);
       J_on(tgt_no)     = pa_T(14,i);              % sec
       J_off(tgt_no)    = pa_T(15,i);              % sec
     end;
   end;

%  set text color for  field name

black  =[0    0    0   ]; white   =[1 1    1   ];
red    =[0.75 0    0   ]; green   =[0 0.75 0   ];
yellow =[0.75 0.75 0   ]; lt_blue =[0 0.75 0.75];
gray   =[0.75 0.75 0.75]; blue    =[0 0    0.75];
dk_gray=[0.6  0.6  0.6 ]; dk_green=[0 0.25 0   ];

tgt_color(1,:)=[0 1 0];
tgt_color(2,:)=[1 1 0];
tgt_color(3,:)=[1 0 0];

fig_ppi=figure('NumberTitle','off','Name','Target Trajectory',...
               'Color',dk_gray,'Position',[50 50 550 550],...
               'Resize','off','MenuBar','none');
```

```
figure(fig_ppi);
hold on;

%
%   Create PPI Display
%

Rmark=(Rmax-Rmin)/5;          % range marker resolution (m)

az_mark=1;                    % azimuth marker resolution (deg)

disp_rad=150;                 % display circle radius (pixels)
disp_dr=disp_rad/Rmax;        % pixels/m;


Rg=disp_rad; cx=0; cy=0;
plot(cx,cy,'.','Color',black,'MarkerSize',680);     % inner scope
ang0=0:pi/180:2*pi;
px=cx+Rg*cos(ang0); py=cy+Rg*sin(ang0);
plot(px,py,'Color',dk_green,'LineWidth',10);        % outer ring

L1=[disp_rad disp_rad+5];
ang1=pi/180*az_mark:pi/180*az_mark:2*pi;            % azimuth marker
rx=cx+L1'*cos(ang1); ry=cy+L1'*sin(ang1);
plot(rx,ry,'Color',green,'LineWidth',1);

L1=[disp_rad-4 disp_rad+5];                         % azimuth marker
ang1=pi/180*15:pi/180*15:2*pi;                      % every 15 deg
rx=cx+L1'*cos(ang1); ry=cy+L1'*sin(ang1);
plot(rx,ry,'Color',green,'LineWidth',2);

rx=[-(disp_rad-4) disp_rad-4]; ry=[cy cy];          % x-y axes dash line marker
plot(rx,ry,'Color',green,'LineWidth',1,'LineStyle',':');
rx=[cx cx]; ry=[disp_rad-4 -(disp_rad-4)];
plot(rx,ry,'Color',green,'LineWidth',1,'LineStyle',':');

text(-5,170,'0','FontSize',10,'Color',white');      % azimuth marker
text(165,0,'90','FontSize',10,'Color',white');      % 0,90,180,270 deg
text(-12,-170,'180','FontSize',10,'Color',white');
text(-188,0,'270','FontSize',10,'Color',white');

ang0=0:pi/180:2*pi;                                 % range marker
mk_dr=disp_dr*Rmark;
mk_no=Rmax/Rmark-1;
L0=[mk_dr:mk_dr:mk_no*mk_dr];
px=cx+cos(ang0)'*L0; py=cy+sin(ang0)'*L0;
plot(px,py,'Color',green,'LineWidth',1);

lx=disp_rad+15;  ly=disp_rad+15;
axis([-lx lx -ly ly]);
axis('equal');
axis('off');



%
% initialize the MainBeam scan line (Timer Control)
%
Rg=[0,146];
lx=cx-cos(90*deg2rad)*Rg;
ly=cy+sin(90*deg2rad)*Rg;
hndl_sl=plot(lx,ly,'Color',[0 1 0],'EraseMode','Xor','LineWidth',2);
```

```
%
% initialize the target (dot) (Timer Control)
%

for i=1:tgt_no
   hndl_tgt(i)=plot(cx,cy,'.','Color',tgt_color(1,:),...
                     'EraseMode','xor','MarkerSize',20);
   if J_type(i) ~= 0
      on_flag(i)=0;
   end
end;


%
%-------------  clock timer display  --------------------------------
%
         uicontrol(gcf,'Style','text',...
              'BackG',black,'ForeG',black,'Position',[ 29 519 142 22]);
         uicontrol(gcf,'Style','text','String','Timer (sec):',...
              'BackG',white,'ForeG',black,'Position',[ 30 520 100 20]);
hndl_clk=uicontrol(gcf,'Style','text','String','0.0',...
              'BackG',white,'ForeG',black,'Position',[130 520  40 20]);
%
%-------------  display max range setting  --------------------------
%
         uicontrol(gcf,'Style','text',...
              'BackG',black,'ForeG',black,'Position',[329 519 142 22]);
         uicontrol(gcf,'Style','text','String','Range (NM):',...
              'BackG',white,'ForeG',black,'Position',[330 520 100 20]);
set_Rmax=uicontrol(gcf,'Style','edit','String',num2str(Rmax/1.852e3),...
              'BackG',white,'ForeG',black,'Position',[430 520  40 20],...
 'Callback',['Rmax=str2num(get(set_Rmax,''String''))*1e3;',...
             'Rmark=Rmax/5;','disp_dr=disp_rad/Rmax;']);

%------------  display control pushbutton ----------------------------

uicontrol(gcf,'Style','text','Position',[ 140 15 300 35],'BackG',white);
uicontrol(gcf,'Style','text','Position',[ 142 17 296 31],'BackG',black);

uicontrol(gcf,'Style','pushbutton','Position',[150 20 130 25],...
              'String','Show Trails', 'CallBack','sce_2112');

uicontrol(gcf,'Style','pushbutton','Position',[300 20 130 25],...
              'String','Clear Trails','CallBack','sce_2113');

%
%  call simulink
%

sce_211;

end;
```

```
function [disp_dr]=sce_2111(t)
%
% sce_2111
%
% target trajectory update
%
% called by sce_211 (simulink)
%

global T_Range; global T_Az; global T_Alt; global T_Speed; global T_Head;
global J_type; global J_on; global J_off;

global J_type; global J_on; global J_off; global tgt_color; global on_flag;
global Scan_rate; global tgt_no; global disp_dr;
global hndl_tgt; global hndl_sl; global hndl_clk;

deg2rad=pi/180;  rad2deg=180/pi;

  set(hndl_clk,'String',num2str(t));

  for j=1:tgt_no
      tx=(T_Range(j)*disp_dr)*sin(T_Az(j)*deg2rad)+...
          T_Speed(j)*disp_dr*t*sin(T_Head(j)*deg2rad);
      ty=(T_Range(j)*disp_dr)*cos(T_Az(j)*deg2rad)+...
          T_Speed(j)*disp_dr*t*cos(T_Head(j)*deg2rad);
      Rxy=abs(tx+1j*ty);

      if Rxy > 146
           tx=0; ty=0;
      end;

      set(hndl_tgt(j),'Xdata',tx,'Ydata',ty);

      if J_type(j) ~= 0;
         if (J_on(j)< t) & (t< J_off(j)) & (on_flag(j)==0)
            set(hndl_tgt(j),'Color',tgt_color(J_type(j)+1,:));
            on_flag(j)=1;
         end;
         if (J_off(j)< t) & (on_flag(j)==1)
            set(hndl_tgt(j),'Color',tgt_color(1,:));
            on_flag(j)=0;
         end;
      end
  end;

    DRu=[0,146];
    lx=-cos((t*Scan_rate+90)*deg2rad)*DRu;
    ly= sin((t*Scan_rate+90)*deg2rad)*DRu;

    set(hndl_sl,'Xdata',lx,'Ydata',ly);
    drawnow;

end;
```

```
% sce_2112
%
% Traget Trajectory [ show trails ] control
%

for i=1:tgt_no
   set(hndl_tgt(i),'EraseMode','none');
end;

end;
```

```
% sce_2113
%
% Target Trajectory [ Clear Trail ] display control
%

figure(fig_ppi);
hold on;

%
%   Create PPI Display
%

Rg=disp_rad; cx=0; cy=0;
plot(cx,cy,'.','Color',black,'MarkerSize',680);   % inner scope

rx=[-(disp_rad-4) disp_rad-4]; ry=[cy cy];        % x-y axes dash line marker
plot(rx,ry,'Color',green,'LineWidth',1,'LineStyle',':');
rx=[cx cx]; ry=[disp_rad-4 -(disp_rad-4)];
plot(rx,ry,'Color',green,'LineWidth',1,'LineStyle',':');

ang0=0:pi/180:2*pi;                                % range marker
mk_dr=disp_dr*Rmark;
mk_no=Rmax/Rmark-1;
L0=[mk_dr:mk_dr:mk_no*mk_dr];
px=cx+cos(ang0)'*L0; py=cy+sin(ang0)'*L0;
plot(px,py,'Color',green,'LineWidth',1);

%
% initialize the MainBeam scan line (Timer Control)
%
Rg=[0,146];
lx=cx-cos(90*deg2rad)*Rg;
ly=cy+sin(90*deg2rad)*Rg;
hndl_sl=plot(lx,ly,'Color',[0 1 0],'EraseMode','Xor','LineWidth',2);


for i=1:tgt_no
   set(hndl_tgt(i),'Xdata',cx,'Ydata',cy,'Color',tgt_color(1,:),...
                   'EraseMode','xor');
   if J_type(i) ~= 0
      on_flag(i)=0;
   end
end;

end;
```

```
function sce_22
%
% sce_22
%
% SEENARIO DEFINITION
%                    -- Definition
%                            -- Traget RCS Fluctuation
%
%
%
%  Display Traget RCS Fluctuation Model
%

%
% Sweling case
% (0)   non-fluctuating, single isotropic scatters
% (1) large-fluctuating, slow complex targets
% (2) large-fluctuating, fast complex targets
% (3) small-fluctuating, slow simpler targets
% (4) small-fluctuating, fast simpler targets
%

ndt=10000;
sn=100;

% ---- Swerling case 1 & 2 ------

RCS_av=100;
df=2;          % k=1, df=2k;
A=1;
B=RCS_av;

% Generate Gamma random RCS
fig_r1=figure('NumberTitle','off','Name','Random Variable (k=1)',...
              'MenuBar','none','Position',[25 425 480 200]);
figure(fig_r1);
RCS=gamrnd(A,B,1,ndt);
for i=1:sn
  line([i i],[RCS(i) 0]);
end;
Rmin=min(RCS(1:sn));
Rmax=max(RCS(1:sn));
axis([1 sn Rmin Rmax]);
title('Random Variable (k=1)');
grid;  xlabel('Pulse');  ylabel('RCS (m^2)');

%
% Fluctuation Chi-Square PDF
%

fig_r2=figure('NumberTitle','off','Name','Chi-square pdf (k=1)',...
              'MenuBar','none','Position',[25 185 480 200]);
figure(fig_r2);
Y=chi2pdf(RCS,df);
plot(RCS,Y,'.');
grid;   axis([0 10 0 0.5]);
title('Chi-square pdf (k=1)');
xlabel('X^2');  ylabel('f(X^2)');


% ---- Swerling case 3 & 4 ------

RCS_av=100;
```

```
df=4;          % k=2, df=4;
A=2;
B=RCS_av/2;

% Generate Gamma random RCS

fig_r3=figure('NumberTitle','off','Name','Random Variable (k=2)',...
              'MenuBar','none','Position',[535 425 480 200]);
figure(fig_r3);
RCS=gamrnd(A,B,1,ndt);
for i=1:sn
  line([i i],[RCS(i) 0]);
end;
axis([1 sn Rmin Rmax]);
title('Random Variable (k=2)');
grid; xlabel('Pulse');  ylabel('RCS (m^2)');

%
% RCS Fluctuation Chi-Square PDF
%
fig_r4=figure('NumberTitle','off','Name','Chi-square pdf (k=2)',...
              'MenuBar','none','Position',[535 185 480 200]);
figure(fig_r4);
Y=chi2pdf(RCS,df);
plot(RCS,Y,'.');
grid;   axis([0 10 0 0.5]);
title('Chi-square pdf (k=2)');
xlabel('X^2');  ylabel('f(X^2)');

end;
```

```
function sce_23
%
% sce_23
%
% SEENARIO DEFINITION
%                   -- Definition
%                           -- Jammer Characteristics
%
%

end;
```

```
function sce_24
%
% sce_24
%
% SEENARIO DEFINITION
%                   -- Definition
%                           -- Clutter Map
%

end;
```

```
% enviro
%
% RADAR ECHO SIMULATION Worksheet
%
% File        env_11 | Open...        |
%                 12 | Save as...     |
%
% Simulation  env_21 | Echo Simulation   |
%                    | Echo Verification |
%             env_22     | Amp. (Zero Threshold)  |
%             env_23     | Amp. (Fixed Threshold) |
%             env_24     | Doppler Frequency      |
%
%

%-----------  create pop-up menu ------------------------------------------

fig_env=figure('NumberTitle','off','Name','RADAR ECHO SIMULATION',...
               'MenuBar','none','Resize','off','Position',[37 157 610 500]);

env_op1=uimenu(gcf,'Label','File');
        uimenu(env_op1,'Label','Open...',                'CallBack','env_11');
        uimenu(env_op1,'Label','Save As...',             'CallBack','env_12');


env_op2=uimenu(gcf,'Label','Simulation');
        uimenu(env_op2,'Label', 'Echo Simulation',       'CallBack','env_21');
env_op2a=uimenu(env_op2,'Label','Echo Verification');
        uimenu(env_op2a,'Label','Amp. (Zero Threshold)', 'CallBack','env_22');
        uimenu(env_op2a,'Label','Amp. (Fixed Threshold)','CallBack','env_23');
        uimenu(env_op2a,'Label','Doppler Frequency',     'CallBack','env_24');

end;
```

```
% env_11
%
% RADAR ECHO SIMULATION
%                               -- File
%                                         -- Open...
%
%
%

%------------  create file open window ---------------------------------------

fig_open=figure('NumberTitle','off','Name','Open','Color',[1 1 1],...
                'MenuBar','none','Position',[200 400 350 180]);
 rpa_file='';
 uicontrol(gcf,'Style','text','String','Radar Model',...
                'BackG',[1 1 1],'ForeG',[0 0 1],'Position',[45 150 100 20]);
 uicontrol(gcf,'Style','text','String','File Name:',...
                'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[45 135 100 20]);
 uicontrol(gcf,'Style','text','String','',...
                'BackG',[0 0 0],'Position',[50  100 100 36]);
 uicontrol(gcf,'Style','text','String','',...
                'BackG',[1 1 1],'Position',[51  101  98 34]);
 ed_rpa_file=uicontrol(gcf,'Style','edit','String',rpa_file,...
                'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[56 101 90 26],...
                'Callback',['rpa_file=get(ed_rpa_file,''String'');']);
 tpa_file='';
 uicontrol(gcf,'Style','text','String','Scenario',...
               'BackG',[1 1 1],'ForeG',[0.75 0 0],'Position',[45  70 100 20]);
 uicontrol(gcf,'Style','text','String','File Name:',...
                'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[45  55 100 20]);
 uicontrol(gcf,'Style','text','String','',...
                'BackG',[0 0 0],'Position',[50  20 100 36]);
 uicontrol(gcf,'Style','text','String','',...
                'BackG',[1 1 1],'Position',[51  21  98 34]);
 ed_tpa_file=uicontrol(gcf,'Style','edit','String',tpa_file,...
                'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[56 21 90 26],...
                'Callback',['tpa_file=get(ed_tpa_file,''String'');']);

%------------  create file selection pushbutton ------------------------------

uicontrol(gcf,'Style','pushbutton','Position',[250 100 80  30],...
              'String','OK',...
              'CallBack',['delete(fig_open)',';','env_111']);

uicontrol(gcf,'Style','pushbutton','Position',[250  50 80  30],...
              'String','Cancel','CallBack','delete(fig_open);');

end;
```

```
% env_111
%
% RADAR ECHO SIMULATION
%                              -- File
%                                      -- Open file
%
%
%
%  open   radar model file (rpa_file)
%         scenario    file (tpa_file)
%
%  create echo simulation coverage edit worksheet


%------- file handle (radar model file) ------------------------------

eval(['load d:\matlab\bin\chen\thesis\',rpa_file,';']);


%  set text strings of opened file name

item_file='Radar Model File:';
item_sys ='Radar System:';

%  set text color for  field name

black =[0    0    0   ]; white  =[1 1    1   ];
red   =[0.75 0    0   ]; green  =[0 0.75 0   ];
yellow=[0.75 0.75 0   ]; lt_blue=[0 0.75 0.75];
gray  =[0.75 0.75 0.75]; blue   =[0 0    0.75];


%  set edit field size

tw=170;            % width for item name
th=23;             % heigh for item name (parameter)
td=25;             % vertical distance between two item (parameter) td > th
aw=50;             % width for parameter


tx=50; ty=450;     % initial position for 1st item name (left,top)

uicontrol(gcf,'Style','text','String',item_file,...
              'BackG',blue,'ForeG',white,'Position',[tx ty 150 td]);
uicontrol(gcf,'Style','text','String',pa_file,...
              'BackG',blue,'ForeG',white,'Position',[tx+150 ty 75 td]);


tx=310; ty=450;    % initial position for 1st item name (left,top)

uicontrol(gcf,'Style','text','String',item_sys,...
              'BackG',blue,'ForeG',white,'Position',[tx ty 120 td]);
uicontrol(gcf,'Style','text','String',pa_sys,...
              'BackG',blue,'ForeG',white,'Position',[tx+120 ty 150 td]);


%------- file handle (scenario file) ------------------------------------

eval(['load d:\matlab\bin\chen\thesis\',tpa_file,';']);


%  set text strings of opened file name
```

```
item_file='Scenario File:';

tx=50; ty=420;     % initial position for 1st item name (left,top)

uicontrol(gcf,'Style','text','String',item_file,...
              'BackG',blue,'ForeG',white,'Position',[tx ty 150 td]);
uicontrol(gcf,'Style','text','String',pa_file,...
              'BackG',blue,'ForeG',white,'Position',[tx+150 ty 75 td]);

%
% ---- set echo simulation coverage -------------
%

%  set strings item_name

e_titl='Echo Simulation Coverage';
e_name(1,:)='Scan Sector     (deg)';
e_name(2,:)='Detection Range  (NM)';


% default coverage


e_pa(1)=25;                 % sector default 0-25 deg
e_pa(2)=pa_D(8);            % Rmax (NM) = Display Range



%  establish edit worksheet

tx=50; ty=350;     % initial position for 1st item name (left,top)

  uicontrol(gcf,'Style','text','String',e_titl,...
              'BackG',green,'ForeG',white,'Position',[tx ty+td tw+aw+2 th]);
  for i=1:2
    uicontrol(gcf,'Style','text','String',e_name(i,:),...
              'BackG',gray, 'Position',[tx ty-(i-1)*td tw th]);

    ed_e_pa(i)=uicontrol(gcf,'Style','edit','String',num2str(e_pa(i)),...
              'BackG',white,'Position',[tx+tw+2 ty-(i-1)*td aw th],...
              'Callback',...
  ['e_pa(',num2str(i),')=str2num(get(ed_e_pa(',num2str(i),'),''String''));']);
  end;

%------------  creat Make selection pushbutton ---------------------------

cp_x=230; cp_y=80; cp_w=180; cp_d=35;

uicontrol(gcf,'Style','push','String','Echo Simulation',...
                    'Position',[cp_x-1 cp_y+40 cp_w cp_d],...
                    'CallBack','env_21');

end;
```

```
% env_12
%
% RADAR ECHO SIMULATION
%                                 -- File
%                                          -- Save As...
%

%------------  create file Save As window ----------------------------------------

pa_file='';
fig_save_as=figure('NumberTitle','off','Name','Save As','Color',[1 1 1],...
                'MenuBar','none','Position',[280 200 350 180]);

 uicontrol(gcf,'Style','text','String','Radar Echo',...
             'BackG',[1 1 1],'ForeG',[0 0.75 0],'Position',[45 100 100 30]);
 uicontrol(gcf,'Style','text','String','File Name:',...
                'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[45  75 100 30]);
 uicontrol(gcf,'Style','text','String','',...
               'BackG',[0 0 0],'Position',[50  50 100 36]);
 uicontrol(gcf,'Style','text','String','',...
               'BackG',[1 1 1],'Position',[51  51  98 34]);
 ed_pa_file=uicontrol(gcf,'Style','edit','String',pa_file,...
               'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[56 51 90 26],...
               'Callback',['pa_file=get(ed_pa_file,''String'');']);

%------------  create file selection pushbutton ------------------------------

uicontrol(gcf,'Style','pushbutton','Position',[200 100  80  30],...
         'String','Save', 'CallBack',['delete(fig_save_as)',';','env_121']);

uicontrol(gcf,'Style','pushbutton','Position',[200 50  80  30],...
         'String','Cancel','CallBack','delete(fig_save_as);');
end;
```

```
% env_121
%
% RADAR ECHO SIMULATION
%                                 -- File
%                                          -- Save file
%

s_pa=...
'env_sec env_rg SIQ pw prf FFTn VT_fixed dAZ PC_no RB_no Ru Scan_rate
RRE_coef';

eval(['save d:\matlab\bin\chen\thesis\',pa_file,' pa_file e_pa ',s_pa,';']);


end;
```

```
% env_21
%
% RADAR ECHO SIMULATION
%                        -- Simulation
%                                -- Echo Simulation
%
% Make Radar Echo with noise at time base
%
% (sampled moving taregt's I,Q video)
%

No_tgt=5;

deg2rad=pi/180;  rad2deg=180/pi;

%--- get radar model parameter -----------------------------------

     f        = pa_A(1)*1e6;           % Hz   <-- MHz
     f0       = pa_A(2)*1e6;           % Hz   <-- MHz
     prf      = pa_A(3)*1e3;           % Hz   <-- KHz
     Pt       = pa_A(4)*1e3;           % watt <-- Kw
     pw       = pa_A(5)*1e-6;          % sec  <-- us
     TR       = pa_A(6)*1e-6;          % sec  <-- us
     ts       = pa_A(7)*1e-6;          % sec  <-- us

     Gt         = pa_B(1);             % dB
     HPBW       = pa_B(2);             % deg
     Scan_rate  = pa_B(3)*6;           % deg/sec <-- RPM
     EL_up      = pa_B(4);             % deg

     Ls       = pa_C(1);               % dB
     Lt       = pa_C(2);               % dB
     Lr       = pa_C(3);               % dB
     Ts       = pa_C(4);               % deg K
     Ta       = pa_C(5);               % deg K
     Ta1      = pa_C(6);               % deg K
     Tr       = pa_C(7);               % deg K
     Te       = pa_C(8);               % deg K
     Bn       = pa_C(9)*1e6;           % Hz   <-- MHz
     Fn       = pa_C(10);
     Pfa      = pa_C(11);
     Aif      = 10^(pa_C(12)/10);      % normal <-- dB

     Vmax     = pa_D(1);               % Volt
     Vmin     = pa_D(2);               % Volt
     ADn      = pa_D(3);
     FFTn     = pa_D(4);
     dAZ      = pa_D(5);               % deg
     CFAR2n   = pa_D(6);
     CFARm    = pa_D(7);
     Rdisp    = pa_D(8)*1.852e3;       % m    <-- Nm


%--- get scenario parameter ----------------------------

  tgt_no=0;

  for i=1:No_tgt
     if pa_T(1,i) ~= 0
       tgt_no=tgt_no+1;
       T_Range(tgt_no)    = pa_T(1,i)*1.852e3;        % m <-- NM
       T_Az(tgt_no)       = pa_T(2,i);                % deg
       T_Alt(tgt_no)      = pa_T(3,i)*0.3048;         % m     <-- ft
```

```
      T_Head(tgt_no)    = pa_T(4,i);                % deg
      T_Speed(tgt_no)   = pa_T(5,i)*1.852e3/3600;   % m/sec <-- Knots
      T_RCS(tgt_no)     = pa_T(6,i);                % m^2
      T_RCSm(tgt_no)    = pa_T(7,i);

      J_type(tgt_no)    = pa_T(8,i);
      J_Pj(tgt_no)      = pa_T(9,i)*1e3;            % watt <-- Kw
      J_Gj(tgt_no)      = pa_T(10,i);               % dB
      J_Bj(tgt_no)      = pa_T(11,i)*1e6;           % Hz <-- MHz
      J_prf(tgt_no)     = pa_T(13,i)*1e3;           % Hz <-- KHz
      J_loss(tgt_no)    = pa_T(14,i);               % dB
      J_on(tgt_no)      = pa_T(14,i);               % sec
      J_off(tgt_no)     = pa_T(15,i);               % sec
    end;
  end;


% -----  set-up Antenna Gain Table -------------------------------

  GAZ=ant_gaz(0);         % dB
  GEL=ant_gel(0);         % dB

%-----------------------------------------------------------------


    k_Boltz=1.38e-23;     % Boltzmann's constant
    T0=290;               % standard temperature (deg K)

    Ru  =3e8/(2*prf);     % m
    Rmax=Ru;              % m
    Rmin=3e8*(pw+TR)/2;   % m
    dR=3e8*pw/2;          % m
    wl=3e8/f;             % wavelength (m)

    if Ls == 0
       Ls=Lt+Lr;                                 % dB
    end;
    Ls=10^(Ls/10);                               % normal <-- dB

    Dtheta=Scan_rate/prf;                        % pulse increment angle
    RRE_coef=Pt*wl*wl/(Ls*(4*pi)^3);             % radar range equation coef.

    if Ta == 0
       Ta=0.876*Ta1+36;                          % deg K
    end;

    if Ts == 0
       Ts=Ta+Tr+10^(Lr/10)*Te;                   % deg K
    end;
    if Ts == 0
       Pn=k_Boltz*T0*Bn*Fn;                      % watt
    else
       Pn=k_Boltz*Ts*Bn;                         % watt
    end;


%     Vmax=Aif*sqrt(Pmax);
%     Vmin=Aif*sqrt(Pmin);

      Vn  =Aif*sqrt(Pn);

%--- get eecho simulation coverage -------------------------------
```

```
 env_sec= e_pa(1);                              % deg
 env_rg = e_pa(2);                              % NM

 PC_no=round((env_sec)/Dtheta);                 % Pulse no.
 RB_no=round((env_rg*1.852e3-Rmin)/dR);         % Range bin no.
 Ru=RB_no*dR;                                   % Unambiguious Range


%
% compute scan main beam angle (degree)
% compute moving target position (tgt_range,tgt_bearing) at time base
% Sampled I & Q data generation (Square Waveform)
%
%

%  display the radar echo making status

cp_x=230; cp_y=95; cp_w=178;

mk_bar2=uicontrol(gcf,'Style','text','BackG',red,...
                  'String','',...
                  'Position',[cp_x   cp_y   0.1    20]);

mk_bar1=uicontrol(gcf,'Style','text','BackG',white,...
                  'Position',[cp_x   cp_y   cp_w   20]);

mk_bar0=uicontrol(gcf,'Style','text','BackG',gray,...
                  'Position',[cp_x-2 cp_y-2 cp_w+4 24]);

mk_pn=0;       % reset making status = 0%



dt=1/prf;
M=RB_no;                                      % (200)   => 300m*500=150Km=80NM
N=PC_no;                                      % (5000)  => 0.072*5000=360deg

Dfd=prf/FFTn;                                 % Doppler freq. resolution
SIQ=zeros(N,M); fdp=zeros(N,M);
sd=pw/2;


% -----  set-up Random Noise Voltage Table ------------------------------

  Vn_I=Vn*randn(N,M);
  Vn_Q=Vn*randn(N,M);
  SIQ=Vn_I+1j*Vn_Q;

%-----------------------------------------------------------------------

if tgt_no ~= 0

for j=1:tgt_no                                    % initial target trajectory
    Rt(j)=T_Range(j);
    AZt(j)=T_Az(j);
    ELt(j)=asin(T_Alt(j)/Rt(j))*rad2deg;
    dX(j)=T_Speed(j)*dt*sin(T_Head(j)*deg2rad);
    dY(j)=T_Speed(j)*dt*cos(T_Head(j)*deg2rad);
end;
```

```
for i=1:N

  mk_pn=i/N;
  set(mk_bar2,'Position',[cp_x cp_y cp_w*mk_pn 20]);

  t=dt*(i-1);

  M_Beam=Scan_rate*t;                              % mainbeam -30dB coverage
    if M_Beam >= 360
       M_Beam=M_Beam-floor(M_Beam/360)*360;        % keep in 360 deg
    end


   for j=1:tgt_no                                  % target current position

     Xt=Rt(j)*cos(ELt(j)*deg2rad)*sin(AZt(j)*deg2rad)+dX(j);
     Yt=Rt(j)*cos(ELt(j)*deg2rad)*cos(AZt(j)*deg2rad)+dY(j);
     Rt(j)=sqrt(Xt*Xt+Yt*Yt+ELt(j)*ELt(j));
     Sxy=Yt+1j*Xt;
     Rt(j)=abs(Sxy);
     AZt(j)=angle(Sxy)*rad2deg;
       if AZt(j) <0;
          AZt(j)=AZt(j)+360;
       end
     ELt(j)=asin(T_Alt(j)/Rt(j))*rad2deg;

     beam_dif=AZt(j)-M_Beam;
       if beam_dif >= 180
          beam_dif=beam_dif-360;
       end
       if beam_dif <= -180
          beam_dif=beam_dif+360;
       end


     tgt_az=ceil(beam_dif/Dtheta)+2500;          % GAZ table resolution: Dtheta
     if (tgt_az <= 0) | (tgt_az > 2500)          % start from -180 deg
        tgt_az = 1;
     end;

     tgt_el=ceil(ELt(j)-EL_up)+20;               % GEL table resolution: 1 deg
     if (tgt_el <= 0) | (tgt_el > 60)            % start from -20 deg
        tgt_el = 1;
     end;


     tgt_gain=Gt+GAZ(tgt_az)+GEL(tgt_el);
     tgt_gain=10^(tgt_gain/10);                  % normal <-- dB
     tgt_RCS=T_RCS(j);                           % assume RCSm=0; constant RCS

     Ps=RRE_coef*tgt_gain^2*tgt_RCS/Rt(j)^4;
     Vs=Aif*sqrt(Ps);

     tgt_rcell=ceil((Rt(j)-Rmin)/dR);
       if tgt_rcell <= 0
          tgt_rcell = 1;
       end;
     Vs=Vs+abs(SIQ(i,tgt_rcell));                % Vs=Vs+Vn
       if Vs > Vmax
          Vs=Vmax;
       end;

 % LPF filted SIQ=I+iQ channel output SIQ(1,1:M) .... SIQ(N,1:M)
```

```
      tgt_fd=-2*T_Speed(j)*cos((T_Head(j)-M_Beam)*deg2rad)/wl;

      SIQ(i,tgt_rcell)=0.5*Vs*exp(1j*2*pi*tgt_fd*(sd+t));    % Voltage

   end  % (j)


end     % (i)

end;  %( if tgt_no ~=0 )


% ----------------  A/D Converter ---------------------

      Amp=abs(SIQ);
      Vmax=max(max(Amp));
      Vmin=min(min(Amp));
      dV=(Vmax-Vmin)/(2^ADn-1);

      T_fixed=sqrt(-2*log(Pfa));
      VT_fixed=round((T_fixed*Vn-Vmin)/dV);

   SI=round((real(SIQ)-Vmin)/dV);
   SQ=round((imag(SIQ)-Vmin)/dV);
   SIQ=SI+1j*SQ;
   Amp=abs(SIQ);


delete(mk_bar2); delete(mk_bar1); delete(mk_bar0);


%
% ---- Select Radar Echo Plotting Range & Sector Coverge -------------
%

%  set strings item_name ;

p_titl='Echo Verification Coverage';
p_name(1,:)='Sector min (deg)';
p_name(2,:)='Sector max (deg)';
p_name(3,:)='Range  min  (NM)';
p_name(4,:)='Range  max  (NM)';
p_name(5,:)='Amp.  min  (A/D)';
p_name(6,:)='Amp.  max  (A/D)';

p_pa(1)=0;
p_pa(2)=env_sec;
p_pa(3)=Rmin/1.852e3;             %  Rmin (NM)
p_pa(4)=env_rg;
p_pa(5)=ceil(min(min(Amp)));
p_pa(6)=ceil(max(max(Amp)));


%  set edit field size

tw=140;             % width for item name
th=23;              % heigh for item name (parameter)
td=25;              % vertical distance between two item (parameter) td > th
aw=80;              % width for parameter

tx=310; ty=350;     % initial position for 1st item name (left,top)

  uicontrol(gcf,'Style','text','String',p_titl,...
```

```
              'BackG',red,'ForeG',white,'Position',[tx ty+td tw+aw+2 th]);
  for i=1:6
    uicontrol(gcf,'Style','text','String',p_name(i,:),...
              'BackG',gray, 'Position',[tx ty-(i-1)*td tw th]);

    ed_p_pa(i)=uicontrol(gcf,'Style','edit','String',num2str(p_pa(i)),...
              'BackG',white,'Position',[tx+tw+2 ty-(i-1)*td aw th],...
              'Callback',...
  ['p_pa(',num2str(i),')=str2num(get(ed_p_pa(',num2str(i),'),''String''));']);
  end;

%------------  create plot selection pushbutton ---------------------------

uicontrol(gcf,'Style','text','Position',[  46  5 530 40],'BackG',white);
uicontrol(gcf,'Style','text','Position',[  48  7 526 36],'BackG',black);
uicontrol(gcf,'Style','text','Position',[ 230 30 150 25],...
             'String','Echo Verification','BackG',black,'ForeG',white);

uicontrol(gcf,'Style','pushbutton','Position',[ 50 10 175 25],...
             'String','Amp. (Zero Threshold)', 'CallBack','env_22');

uicontrol(gcf,'Style','pushbutton','Position',[230 10 175 25],...
             'String','Amp. (Fixed Threshold)','CallBack','env_23');

uicontrol(gcf,'Style','pushbutton','Position',[410 10 160 25],...
             'String','Doppler Frequency',      'CallBack','env_24');

end;
```

```
function [Gr]=ant_gaz(status);
%
% ant_gaz
%
%  status=0, transfer the antenna gain
%         1, plot the antenna pattern
%
%  AN/SPS-49  Reflector Antenna Gain Pattern
%
%  Azimuth: -180 ~ 179, digitized per degree, unit -dB
%
%  Interploation from 1.000 deg (digitized resolution)
%                  to 0.072 deg (radar detection resolution)

AntdB=...
[37.50 37.51 37.53 37.54 37.55 37.57 37.58 37.60 37.61 37.62
 37.64 37.65 37.67 37.69 37.70 37.72 37.74 37.75 37.77 37.79
 37.81 37.83 37.85 37.88 37.90 37.93 37.95 37.98 38.01 38.04
 38.07 38.10 38.13 38.16 38.20 38.23 38.27 38.31 38.35 38.39
 38.43 38.47 38.51 38.56 38.60 38.65 38.69 38.73 38.78 38.82
 38.85 38.89 38.92 38.95 38.97 38.99 39.01 39.01 39.02 39.02
 39.01 39.00 38.98 38.96 38.93 38.90 38.87 38.82 38.78 38.72
 38.67 38.61 38.54 38.47 38.39 38.31 38.23 38.14 38.05 37.96
 37.86 37.75 37.65 37.54 37.42 37.31 37.19 37.07 36.95 36.84
 36.72 36.61 36.49 36.39 36.29 36.19 36.10 36.02 35.94 35.88
 35.82 35.77 35.72 35.68 35.64 35.61 35.59 35.57 35.55 35.53
 35.51 35.50 35.49 35.48 35.47 35.47 35.47 35.48 35.50 35.53
 35.58 35.63 35.70 35.78 35.88 36.00 36.14 36.29 36.46 36.64
 36.83 37.03 37.24 37.44 37.65 37.86 38.06 38.26 38.44 38.62
 38.78 38.93 39.07 39.20 39.31 39.42 39.52 39.61 39.69 39.77
 39.84 39.90 39.96 40.01 40.06 40.11 40.15 40.19 40.22 40.24
 40.26 40.28 40.28 40.28 40.27 40.25 40.22 40.19 40.14 40.09
 40.02 39.95 39.87 39.79 39.70 39.60 39.50 39.40 39.29 39.18
 39.06 38.95 38.83 38.71 38.60 38.48 38.38 38.27 38.18 38.09
 38.01 37.94 37.88 37.84 37.81 37.79 37.80 37.81 37.84 37.88
 37.93 37.99 38.05 38.12 38.19 38.26 38.34 38.41 38.48 38.54
 38.61 38.67 38.73 38.80 38.87 38.95 39.04 39.15 39.27 39.40
 39.56 39.74 39.95 40.18 40.44 40.72 41.00 41.30 41.60 41.90
 42.19 42.47 42.73 42.96 43.17 43.35 43.49 43.58 43.64 43.65
 43.64 43.59 43.51 43.42 43.30 43.17 43.02 42.87 42.71 42.56
 42.40 42.25 42.11 41.97 41.84 41.72 41.61 41.50 41.41 41.33
 41.26 41.20 41.15 41.12 41.10 41.09 41.10 41.13 41.16 41.22
 41.29 41.38 41.49 41.62 41.77 41.93 42.12 42.32 42.55 42.80
 43.07 43.36 43.66 43.97 44.30 44.64 44.99 45.34 45.69 46.05
 46.41 46.76 47.12 47.46 47.80 48.13 48.45 48.76 49.05 49.32
 49.57 49.80 50.00 50.18 50.33 50.45 50.53 50.59 50.61 50.60
 50.56 50.50 50.40 50.29 50.14 49.98 49.79 49.58 49.36 49.11
 48.85 48.58 48.29 48.00 47.69 47.39 47.08 46.77 46.46 46.16
 45.87 45.59 45.33 45.08 44.85 44.64 44.44 44.26 44.10 43.94
 43.80 43.67 43.55 43.44 43.33 43.22 43.12 43.02 42.92 42.82
 42.73 42.63 42.54 42.45 42.37 42.29 42.22 42.16 42.11 42.06
 42.03 42.00 41.99 41.99 41.99 42.01 42.03 42.05 42.08 42.10
 42.13 42.15 42.18 42.19 42.20 42.20 42.19 42.17 42.15 42.11
 42.07 42.02 41.97 41.91 41.84 41.78 41.71 41.64 41.57 41.49
 41.42 41.34 41.27 41.19 41.10 41.01 40.91 40.81 40.70 40.57
 40.44 40.29 40.13 39.96 39.77 39.57 39.36 39.14 38.91 38.68
 38.45 38.22 37.99 37.76 37.54 37.33 37.13 36.94 36.76 36.60
 36.45 36.32 36.20 36.10 36.01 35.93 35.87 35.83 35.80 35.79
 35.79 35.81 35.85 35.89 35.96 36.03 36.11 36.20 36.30 36.40
 36.51 36.62 36.73 36.84 36.95 37.06 37.16 37.27 37.37 37.48
 37.59 37.71 37.84 37.98 38.14 38.31 38.49 38.70 38.92 39.17
 39.43 39.72 40.01 40.31 40.61 40.91 41.19 41.47 41.72 41.96
 42.16 42.34 42.48 42.57 42.63 42.65 42.63 42.59 42.52 42.43
```

42.33	42.21	42.07	41.94	41.79	41.65	41.51	41.39	41.26	41.15
41.05	40.95	40.86	40.79	40.72	40.66	40.61	40.57	40.53	40.51
40.50	40.50	40.50	40.52	40.54	40.57	40.60	40.64	40.69	40.74
40.79	40.84	40.90	40.95	41.01	41.06	41.11	41.17	41.23	41.28
41.35	41.41	41.48	41.55	41.63	41.72	41.81	41.91	42.03	42.14
42.27	42.41	42.55	42.69	42.84	42.99	43.15	43.30	43.45	43.61
43.76	43.90	44.05	44.18	44.32	44.44	44.56	44.67	44.77	44.86
44.94	45.02	45.08	45.13	45.17	45.19	45.20	45.20	45.19	45.16
45.12	45.06	44.99	44.90	44.80	44.69	44.56	44.41	44.26	44.08
43.89	43.69	43.48	43.25	43.03	42.79	42.56	42.32	42.09	41.86
41.64	41.43	41.24	41.06	40.89	40.75	40.61	40.50	40.40	40.31
40.24	40.18	40.13	40.08	40.05	40.03	40.01	40.00	40.00	40.00
40.01	40.02	40.05	40.09	40.14	40.21	40.29	40.39	40.51	40.64
40.80	40.98	41.18	41.40	41.64	41.89	42.15	42.41	42.67	42.93
43.18	43.43	43.65	43.86	44.04	44.20	44.33	44.43	44.50	44.54
44.56	44.57	44.55	44.51	44.45	44.38	44.30	44.20	44.10	43.99
43.87	43.74	43.61	43.48	43.34	43.20	43.05	42.90	42.75	42.60
42.44	42.28	42.12	41.96	41.81	41.65	41.49	41.34	41.18	41.03
40.88	40.74	40.60	40.46	40.33	40.20	40.08	39.96	39.85	39.75
39.65	39.56	39.48	39.40	39.33	39.26	39.20	39.15	39.10	39.05
39.02	38.99	38.96	38.94	38.93	38.92	38.91	38.91	38.91	38.92
38.93	38.94	38.95	38.97	38.99	39.01	39.04	39.06	39.10	39.13
39.18	39.23	39.30	39.37	39.46	39.56	39.67	39.80	39.95	40.11
40.29	40.49	40.71	40.95	41.21	41.48	41.77	42.08	42.41	42.76
43.12	43.51	43.91	44.33	44.76	45.20	45.65	46.09	46.52	46.94
47.33	47.71	48.05	48.35	48.61	48.83	48.99	49.09	49.13	49.13
49.07	48.98	48.85	48.68	48.49	48.27	48.04	47.79	47.53	47.26
47.00	46.74	46.48	46.24	45.99	45.76	45.54	45.32	45.12	44.93
44.75	44.59	44.44	44.30	44.19	44.09	44.01	43.94	43.89	43.84
43.81	43.79	43.78	43.77	43.77	43.78	43.78	43.79	43.80	43.81
43.82	43.83	43.84	43.85	43.87	43.89	43.92	43.95	43.99	44.04
44.09	44.15	44.23	44.31	44.40	44.50	44.60	44.70	44.81	44.92
45.02	45.12	45.22	45.31	45.39	45.46	45.53	45.57	45.61	45.64
45.66	45.67	45.68	45.68	45.67	45.66	45.65	45.63	45.62	45.61
45.59	45.58	45.57	45.56	45.56	45.55	45.55	45.54	45.54	45.53
45.52	45.52	45.51	45.50	45.49	45.48	45.47	45.46	45.45	45.44
45.43	45.42	45.41	45.40	45.40	45.40	45.40	45.40	45.41	45.41
45.42	45.43	45.44	45.45	45.45	45.44	45.43	45.41	45.38	45.33
45.28	45.21	45.12	45.03	44.91	44.79	44.66	44.51	44.36	44.21
44.04	43.88	43.71	43.54	43.37	43.20	43.03	42.87	42.71	42.55
42.39	42.24	42.08	41.92	41.77	41.61	41.46	41.30	41.14	40.98
40.82	40.66	40.50	40.34	40.18	40.02	39.87	39.72	39.58	39.44
39.31	39.19	39.08	38.98	38.89	38.80	38.73	38.67	38.61	38.57
38.52	38.49	38.46	38.44	38.42	38.41	38.40	38.40	38.40	38.40
38.40	38.41	38.42	38.43	38.45	38.46	38.48	38.50	38.53	38.55
38.58	38.61	38.65	38.68	38.71	38.75	38.78	38.82	38.85	38.88
38.91	38.93	38.96	38.98	38.99	39.01	39.01	39.02	39.01	39.01
38.99	38.98	38.96	38.93	38.90	38.86	38.82	38.77	38.72	38.66
38.60	38.53	38.46	38.38	38.30	38.21	38.12	38.03	37.94	37.84
37.74	37.63	37.52	37.42	37.30	37.19	37.08	36.97	36.85	36.74
36.63	36.52	36.41	36.31	36.20	36.11	36.01	35.92	35.83	35.75
35.67	35.59	35.52	35.45	35.38	35.31	35.25	35.18	35.12	35.06
35.00	34.94	34.88	34.82	34.76	34.70	34.64	34.58	34.53	34.47
34.41	34.36	34.30	34.25	34.19	34.14	34.09	34.04	33.99	33.94
33.89	33.84	33.79	33.74	33.69	33.64	33.59	33.54	33.49	33.44
33.39	33.34	33.29	33.24	33.20	33.16	33.12	33.08	33.06	33.03
33.01	33.00	33.00	33.00	33.01	33.03	33.05	33.08	33.11	33.14
33.18	33.21	33.25	33.30	33.34	33.38	33.42	33.46	33.50	33.54
33.58	33.62	33.67	33.72	33.77	33.84	33.90	33.98	34.06	34.16
34.26	34.37	34.49	34.62	34.75	34.88	35.01	35.15	35.28	35.41
35.54	35.66	35.77	35.87	35.96	36.04	36.11	36.16	36.21	36.25
36.28	36.30	36.32	36.33	36.33	36.33	36.32	36.30	36.29	36.26
36.24	36.21	36.17	36.13	36.08	36.02	35.96	35.88	35.80	35.72

35.62	35.51	35.40	35.27	35.14	35.00	34.85	34.71	34.55	34.40
34.25	34.09	33.94	33.79	33.64	33.50	33.36	33.23	33.11	32.99
32.88	32.76	32.66	32.55	32.45	32.36	32.26	32.17	32.08	31.99
31.90	31.81	31.73	31.65	31.57	31.49	31.41	31.34	31.27	31.21
31.15	31.09	31.04	30.99	30.95	30.91	30.88	30.85	30.83	30.81
30.80	30.79	30.78	30.78	30.78	30.79	30.79	30.80	30.82	30.83
30.85	30.87	30.89	30.92	30.94	30.97	30.99	31.02	31.04	31.06
31.09	31.11	31.13	31.15	31.17	31.19	31.21	31.24	31.26	31.29
31.32	31.35	31.39	31.43	31.48	31.53	31.59	31.65	31.71	31.78
31.86	31.93	32.01	32.09	32.17	32.24	32.32	32.40	32.48	32.55
32.62	32.69	32.76	32.83	32.89	32.96	33.03	33.10	33.17	33.24
33.32	33.40	33.48	33.57	33.66	33.75	33.84	33.94	34.03	34.13
34.22	34.31	34.39	34.48	34.56	34.63	34.69	34.75	34.80	34.85
34.89	34.92	34.94	34.97	34.98	34.99	35.00	35.01	35.01	35.00
35.00	34.99	34.98	34.97	34.95	34.93	34.91	34.88	34.84	34.80
34.75	34.70	34.64	34.57	34.49	34.41	34.31	34.22	34.11	34.00
33.89	33.78	33.66	33.54	33.43	33.31	33.20	33.08	32.98	32.87
32.78	32.68	32.59	32.51	32.43	32.36	32.29	32.23	32.17	32.11
32.07	32.02	31.99	31.96	31.93	31.91	31.89	31.88	31.86	31.85
31.84	31.84	31.83	31.82	31.81	31.81	31.80	31.78	31.77	31.76
31.75	31.75	31.74	31.75	31.76	31.78	31.81	31.85	31.90	31.97
32.05	32.14	32.24	32.36	32.49	32.63	32.77	32.93	33.09	33.25
33.42	33.59	33.77	33.94	34.12	34.29	34.46	34.63	34.80	34.97
35.13	35.29	35.45	35.60	35.75	35.89	36.03	36.17	36.30	36.43
36.55	36.67	36.79	36.91	37.03	37.15	37.28	37.40	37.54	37.68
37.83	37.98	38.15	38.32	38.49	38.67	38.85	39.03	39.19	39.36
39.51	39.64	39.76	39.86	39.94	40.00	40.03	40.04	40.02	39.99
39.93	39.86	39.78	39.68	39.58	39.47	39.35	39.23	39.11	38.99
38.87	38.75	38.64	38.53	38.42	38.31	38.20	38.10	37.99	37.89
37.78	37.68	37.58	37.48	37.37	37.27	37.17	37.07	36.97	36.87
36.77	36.68	36.59	36.50	36.41	36.33	36.25	36.18	36.10	36.04
35.97	35.91	35.84	35.78	35.72	35.65	35.58	35.50	35.43	35.34
35.25	35.16	35.05	34.94	34.83	34.72	34.61	34.50	34.40	34.30
34.22	34.14	34.08	34.04	34.01	34.00	34.01	34.03	34.08	34.13
34.20	34.28	34.37	34.46	34.56	34.66	34.76	34.87	34.97	35.06
35.16	35.25	35.33	35.42	35.50	35.58	35.66	35.74	35.83	35.91
36.00	36.09	36.18	36.28	36.38	36.48	36.58	36.69	36.79	36.89
36.98	37.07	37.15	37.23	37.29	37.35	37.40	37.43	37.45	37.46
37.46	37.44	37.42	37.39	37.36	37.31	37.26	37.20	37.14	37.07
37.00	36.93	36.85	36.77	36.69	36.61	36.53	36.45	36.38	36.30
36.23	36.17	36.10	36.05	35.99	35.95	35.91	35.88	35.85	35.83
35.81	35.80	35.79	35.79	35.78	35.79	35.79	35.79	35.80	35.81
35.82	35.83	35.85	35.87	35.89	35.91	35.94	35.98	36.02	36.06
36.11	36.16	36.22	36.29	36.36	36.43	36.51	36.59	36.67	36.75
36.83	36.90	36.98	37.05	37.11	37.17	37.22	37.27	37.30	37.33
37.35	37.36	37.37	37.37	37.36	37.35	37.33	37.30	37.26	37.22
37.17	37.12	37.06	36.99	36.92	36.85	36.77	36.68	36.60	36.51
36.42	36.32	36.23	36.13	36.04	35.94	35.84	35.74	35.64	35.55
35.45	35.36	35.26	35.17	35.08	34.99	34.90	34.82	34.74	34.66
34.58	34.51	34.45	34.39	34.33	34.29	34.25	34.22	34.20	34.19
34.19	34.20	34.22	34.25	34.30	34.35	34.41	34.48	34.55	34.64
34.72	34.81	34.91	35.00	35.10	35.20	35.30	35.40	35.50	35.60
35.71	35.81	35.92	36.03	36.15	36.27	36.40	36.53	36.67	36.82
36.97	37.13	37.29	37.46	37.63	37.80	37.97	38.15	38.32	38.49
38.66	38.82	38.98	39.13	39.28	39.42	39.55	39.68	39.80	39.91
40.01	40.11	40.20	40.28	40.35	40.41	40.47	40.51	40.55	40.58
40.61	40.62	40.63	40.64	40.63	40.62	40.61	40.59	40.57	40.55
40.52	40.49	40.45	40.42	40.38	40.34	40.30	40.26	40.22	40.18
40.14	40.11	40.07	40.04	40.01	39.99	39.96	39.94	39.93	39.92
39.90	39.90	39.89	39.89	39.89	39.89	39.89	39.89	39.90	39.90
39.91	39.92	39.93	39.94	39.95	39.96	39.96	39.97	39.98	39.99
39.99	40.00	40.00	40.00	40.00	40.00	39.99	39.99	39.98	39.98
39.97	39.96	39.95	39.94	39.93	39.91	39.90	39.89	39.88	39.86

39.85	39.84	39.82	39.81	39.80	39.78	39.77	39.75	39.73	39.72
39.70	39.68	39.66	39.65	39.63	39.61	39.59	39.57	39.56	39.54
39.53	39.52	39.51	39.50	39.50	39.50	39.50	39.50	39.51	39.52
39.53	39.54	39.56	39.58	39.60	39.62	39.65	39.68	39.71	39.74
39.77	39.81	39.84	39.88	39.91	39.94	39.96	39.99	40.00	40.01
40.01	40.01	39.99	39.97	39.94	39.90	39.85	39.79	39.73	39.66
39.58	39.49	39.39	39.29	39.18	39.07	38.95	38.82	38.68	38.55
38.40	38.26	38.11	37.96	37.81	37.66	37.51	37.36	37.21	37.06
36.92	36.78	36.64	36.51	36.38	36.26	36.15	36.03	35.93	35.83
35.74	35.66	35.59	35.52	35.46	35.42	35.38	35.35	35.33	35.31
35.31	35.31	35.32	35.34	35.37	35.40	35.44	35.49	35.54	35.60
35.67	35.75	35.83	35.93	36.03	36.14	36.25	36.38	36.52	36.66
36.82	36.98	37.16	37.34	37.53	37.72	37.92	38.12	38.31	38.51
38.70	38.88	39.05	39.21	39.36	39.50	39.62	39.72	39.81	39.89
39.94	39.99	40.02	40.04	40.04	40.04	40.02	39.99	39.95	39.89
39.83	39.76	39.68	39.60	39.50	39.40	39.30	39.19	39.07	38.96
38.84	38.72	38.59	38.47	38.35	38.23	38.11	38.00	37.88	37.77
37.66	37.55	37.44	37.34	37.24	37.15	37.06	36.97	36.89	36.81
36.74	36.67	36.61	36.55	36.49	36.44	36.39	36.34	36.30	36.26
36.22	36.18	36.15	36.13	36.12	36.12	36.14	36.18	36.25	36.34
36.47	36.63	36.83	37.07	37.36	37.69	38.08	38.50	38.98	39.48
40.03	40.61	41.21	41.84	42.50	43.17	43.85	44.55	45.26	45.98
46.69	47.40	48.09	48.77	49.42	50.04	50.63	51.16	51.65	52.08
52.45	52.74	52.96	53.10	53.16	53.15	53.09	52.97	52.80	52.61
52.39	52.15	51.91	51.66	51.43	51.21	51.02	50.86	50.74	50.64
50.57	50.51	50.47	50.43	50.40	50.37	50.33	50.27	50.21	50.12
50.00	49.85	49.68	49.48	49.25	49.00	48.72	48.43	48.12	47.79
47.45	47.09	46.72	46.34	45.96	45.57	45.17	44.77	44.38	43.98
43.60	43.21	42.84	42.48	42.14	41.81	41.50	41.21	40.94	40.70
40.48	40.28	40.10	39.94	39.79	39.66	39.54	39.43	39.32	39.23
39.14	39.06	38.97	38.89	38.81	38.73	38.65	38.57	38.50	38.43
38.35	38.29	38.22	38.15	38.09	38.03	37.98	37.92	37.87	37.82
37.78	37.74	37.70	37.66	37.63	37.60	37.57	37.55	37.53	37.51
37.49	37.48	37.48	37.48	37.49	37.52	37.56	37.62	37.69	37.79
37.91	38.05	38.23	38.43	38.66	38.92	39.20	39.49	39.80	40.11
40.42	40.71	41.00	41.26	41.49	41.70	41.86	41.98	42.05	42.07
42.05	41.99	41.91	41.80	41.67	41.53	41.39	41.25	41.11	40.99
40.89	40.81	40.76	40.75	40.77	40.83	40.93	41.07	41.26	41.49
41.78	42.11	42.50	42.94	43.44	44.00	44.62	45.29	45.99	46.71
47.44	48.16	48.86	49.52	50.14	50.69	51.17	51.56	51.84	52.01
52.05	51.98	51.80	51.52	51.16	50.72	50.22	49.67	49.08	48.45
47.81	47.15	46.50	45.86	45.24	44.64	44.07	43.52	43.00	42.51
42.05	41.61	41.21	40.84	40.51	40.21	39.95	39.73	39.55	39.40
39.28	39.19	39.13	39.09	39.07	39.07	39.08	39.10	39.12	39.15
39.18	39.21	39.24	39.25	39.26	39.27	39.26	39.24	39.21	39.17
39.12	39.05	38.97	38.87	38.76	38.62	38.48	38.33	38.19	38.07
37.99	37.94	37.96	38.03	38.18	38.43	38.76	39.21	39.78	40.48
41.30	42.21	43.18	44.19	45.21	46.22	47.18	48.08	48.88	49.56
50.09	50.44	50.60	50.53	50.25	49.79	49.19	48.47	47.67	46.83
45.96	45.12	44.31	43.59	42.98	42.51	42.22	42.13	42.22	42.47
42.86	43.34	43.91	44.52	45.15	45.77	46.36	46.88	47.32	47.63
47.80	47.80	47.65	47.36	46.94	46.43	45.82	45.15	44.42	43.66
42.88	42.10	41.33	40.61	39.93	39.31	38.76	38.27	37.82	37.42
37.06	36.73	36.43	36.15	35.90	35.65	35.42	35.18	34.95	34.70
34.46	34.22	33.98	33.75	33.54	33.35	33.19	33.05	32.94	32.87
32.84	32.86	32.93	33.05	33.21	33.43	33.68	33.98	34.31	34.67
35.07	35.49	35.94	36.42	36.91	37.41	37.93	38.46	38.99	39.51
40.02	40.50	40.96	41.38	41.75	42.08	42.34	42.54	42.67	42.71
42.66	42.53	42.32	42.04	41.69	41.29	40.85	40.37	39.86	39.33
38.79	38.24	37.70	37.17	36.67	36.18	35.72	35.29	34.87	34.48
34.11	33.76	33.43	33.12	32.83	32.55	32.29	32.05	31.83	31.61
31.41	31.22	31.02	30.83	30.63	30.43	30.21	29.98	29.73	29.46
29.16	28.84	28.48	28.12	27.75	27.42	27.13	26.91	26.77	26.75

26.85 27.10 27.52 28.13 28.95 30.00 31.29 32.78 34.44 36.21
38.04 39.90 41.73 43.49 45.14 46.62 47.90 48.92 49.64 50.02
50.03 49.70 49.08 48.20 47.10 45.84 44.46 42.99 41.47 39.96
38.50 37.11 35.86 34.78 33.89 33.18 32.63 32.23 31.96 31.79
31.70 31.69 31.72 31.79 31.87 31.94 31.99 32.00 31.95 31.84
31.69 31.49 31.23 30.93 30.58 30.19 29.76 29.71 28.90 28.09
27.29 26.50 25.73 24.97 24.22 23.48 22.75 22.03 21.33 20.64
19.95 19.28 18.62 17.98 17.34 16.71 16.10 15.50 14.91 14.33
13.76 13.21 12.66 12.13 11.61 11.10 10.60 10.11 9.64 9.17
8.72 8.28 7.85 7.43 7.02 6.63 6.24 5.87 5.51 5.16
4.82 4.49 4.18 3.87 3.58 3.30 3.03 2.77 2.53 2.29
2.07 1.86 1.66 1.47 1.29 1.12 0.97 0.83 0.69 0.57
0.46 0.37 0.28 0.21 0.14 0.09 0.05 0.02 0.01 0.00
0.01 0.02 0.05 0.09 0.14 0.21 0.28 0.37 0.46 0.57
0.69 0.83 0.97 1.12 1.29 1.47 1.66 1.86 2.07 2.29
2.53 2.77 3.03 3.30 3.58 3.87 4.18 4.49 4.82 5.16
5.51 5.87 6.24 6.63 7.02 7.43 7.85 8.28 8.72 9.17
9.64 10.11 10.60 11.10 11.61 12.13 12.66 13.21 13.76 14.33
14.91 15.50 16.10 16.71 17.34 17.98 18.62 19.28 19.95 20.64
21.33 22.03 22.75 23.48 24.22 24.97 25.73 26.50 27.29 28.09
28.90 29.71 29.68 29.14 29.54 29.90 30.20 30.45 30.63 30.75
30.81 30.80 30.72 30.57 30.34 30.05 29.72 29.38 29.04 28.73
28.46 28.27 28.16 28.18 28.33 28.64 29.12 29.82 30.73 31.84
33.12 34.53 36.04 37.60 39.19 40.76 42.29 43.73 45.05 46.21
47.19 47.93 48.42 48.66 48.68 48.49 48.12 47.58 46.90 46.10
45.21 44.24 43.21 42.14 41.07 40.00 38.96 37.96 37.01 36.13
35.31 34.58 33.95 33.42 33.00 32.72 32.57 32.56 32.72 33.04
33.54 34.19 34.96 35.83 36.77 37.75 38.75 39.75 40.71 41.61
42.42 43.12 43.68 44.07 44.29 44.35 44.28 44.11 43.85 43.54
43.20 42.86 42.53 42.25 42.04 41.92 41.92 42.07 42.36 42.79
43.32 43.93 44.59 45.29 45.99 46.67 47.31 47.88 48.36 48.73
48.95 49.00 48.89 48.62 48.21 47.68 47.05 46.34 45.55 44.71
43.84 42.95 42.06 41.19 40.36 39.57 38.84 38.17 37.56 37.00
36.50 36.04 35.64 35.29 34.99 34.73 34.52 34.35 34.23 34.15
34.11 34.12 34.18 34.28 34.44 34.65 34.92 35.25 35.64 36.09
36.61 37.19 37.84 38.57 39.35 40.18 41.03 41.88 42.73 43.55
44.32 45.02 45.65 46.18 46.59 46.87 47.00 46.96 46.78 46.48
46.10 45.65 45.17 44.68 44.22 43.81 43.47 43.25 43.16 43.23
43.50 43.98 44.64 45.45 46.39 47.41 48.48 49.58 50.66 51.70
52.66 53.50 54.20 54.72 55.02 55.10 54.95 54.62 54.11 53.46
52.68 51.81 50.85 49.84 48.80 47.76 46.72 45.73 44.80 43.94
43.17 42.47 41.84 41.28 40.79 40.38 40.03 39.74 39.51 39.35
39.25 39.20 39.21 39.27 39.38 39.54 39.74 39.97 40.24 40.54
40.87 41.22 41.59 41.97 42.37 42.77 43.18 43.59 43.99 44.38
44.75 45.09 45.41 45.69 45.92 46.11 46.24 46.32 46.32 46.25
46.11 45.89 45.62 45.31 44.97 44.62 44.28 43.96 43.68 43.46
43.30 43.24 43.27 43.42 43.70 44.11 44.62 45.22 45.88 46.58
47.30 48.02 48.72 49.37 49.97 50.47 50.88 51.16 51.29 51.28
51.15 50.90 50.55 50.12 49.60 49.03 48.41 47.76 47.08 46.40
45.73 45.07 44.45 43.86 43.30 42.78 42.30 41.86 41.46 41.10
40.77 40.49 40.25 40.06 39.91 39.80 39.74 39.72 39.73 39.78
39.85 39.95 40.07 40.20 40.33 40.48 40.62 40.76 40.89 41.01
41.11 41.20 41.27 41.32 41.36 41.39 41.40 41.40 41.39 41.37
41.34 41.30 41.24 41.19 41.12 41.05 40.97 40.89 40.80 40.71
40.62 40.52 40.43 40.33 40.24 40.15 40.06 39.97 39.89 39.81
39.74 39.67 39.60 39.53 39.46 39.39 39.32 39.26 39.19 39.12
39.04 38.97 38.89 38.81 38.72 38.64 38.56 38.48 38.40 38.33
38.26 38.19 38.13 38.07 38.02 37.98 37.94 37.91 37.89 37.87
37.86 37.85 37.84 37.84 37.83 37.83 37.82 37.81 37.80 37.79
37.78 37.76 37.74 37.73 37.72 37.72 37.72 37.73 37.76 37.79
37.84 37.90 37.98 38.08 38.19 38.32 38.46 38.61 38.77 38.93
39.09 39.26 39.42 39.57 39.72 39.86 39.99 40.10 40.20 40.28
40.36 40.43 40.49 40.55 40.61 40.67 40.72 40.78 40.85 40.92

41.00	41.09	41.19	41.30	41.41	41.54	41.67	41.80	41.94	42.08
42.23	42.37	42.52	42.67	42.82	42.96	43.10	43.24	43.36	43.47
43.57	43.64	43.70	43.74	43.75	43.73	43.67	43.59	43.47	43.31
43.12	42.90	42.66	42.40	42.12	41.84	41.54	41.25	40.96	40.68
40.41	40.16	39.93	39.72	39.53	39.36	39.21	39.07	38.94	38.82
38.70	38.59	38.47	38.35	38.22	38.08	37.93	37.77	37.60	37.42
37.25	37.07	36.91	36.75	36.60	36.47	36.37	36.28	36.23	36.20
36.21	36.25	36.33	36.43	36.55	36.69	36.84	37.01	37.17	37.34
37.51	37.67	37.82	37.96	38.08	38.17	38.26	38.33	38.39	38.44
38.49	38.54	38.59	38.65	38.71	38.78	38.87	38.97	39.10	39.23
39.39	39.55	39.72	39.89	40.06	40.23	40.40	40.55	40.69	40.81
40.91	40.99	41.04	41.07	41.07	41.05	41.01	40.95	40.87	40.78
40.68	40.56	40.43	40.29	40.15	40.00	39.85	39.69	39.53	39.37
39.21	39.04	38.87	38.69	38.52	38.34	38.15	37.96	37.77	37.58
37.38	37.18	36.98	36.78	36.58	36.38	36.18	35.99	35.80	35.62
35.45	35.28	35.12	34.97	34.83	34.70	34.58	34.47	34.37	34.28
34.21	34.14	34.09	34.05	34.02	34.00	34.00	34.00	34.02	34.05
34.09	34.14	34.20	34.27	34.35	34.43	34.52	34.62	34.72	34.83
34.94	35.05	35.17	35.29	35.41	35.54	35.67	35.81	35.95	36.09
36.25	36.41	36.57	36.74	36.92	37.10	37.29	37.49	37.68	37.88
38.07	38.26	38.43	38.60	38.75	38.89	39.01	39.10	39.18	39.23
39.26	39.26	39.25	39.21	39.16	39.10	39.03	38.95	38.87	38.78
38.69	38.60	38.52	38.44	38.37	38.30	38.24	38.18	38.13	38.08
38.03	37.99	37.95	37.91	37.88	37.84	37.80	37.77	37.73	37.70
37.67	37.64	37.61	37.59	37.57	37.56	37.55	37.55	37.56	37.58
37.60	37.63	37.67	37.72	37.78	37.84	37.91	37.98	38.05	38.12
38.20	38.28	38.36	38.43	38.51	38.58	38.65	38.72	38.79	38.85
38.92	38.99	39.06	39.13	39.20	39.27	39.35	39.43	39.52	39.61
39.71	39.81	39.91	40.01	40.12	40.23	40.35	40.46	40.58	40.69
40.81	40.92	41.04	41.15	41.26	41.37	41.48	41.57	41.66	41.75
41.82	41.88	41.93	41.97	41.99	42.00	41.99	41.97	41.93	41.88
41.82	41.75	41.67	41.58	41.49	41.40	41.30	41.21	41.12	41.04
40.96	40.88	40.82	40.75	40.69	40.63	40.57	40.50	40.44	40.37
40.30	40.22	40.13	40.03	39.93	39.81	39.69	39.56	39.42	39.27
39.12	38.97	38.82	38.66	38.50	38.34	38.19	38.03	37.88	37.74
37.59	37.45	37.32	37.18	37.05	36.92	36.80	36.68	36.56	36.44
36.32	36.21	36.10	36.00	35.89	35.79	35.69	35.60	35.51	35.42
35.34	35.26	35.19	35.12	35.06	35.00	34.95	34.90	34.86	34.83
34.80	34.77	34.75	34.73	34.72	34.71	34.70	34.70	34.70	34.70
34.71	34.71	34.72	34.74	34.75	34.77	34.78	34.80	34.82	34.83
34.85	34.87	34.89	34.90	34.92	34.93	34.95	34.96	34.97	34.98
34.99	34.99	35.00	35.00	35.00	35.00	35.00	35.00	34.99	34.99
34.98	34.98	34.97	34.96	34.96	34.96	34.96	34.96	34.97	34.98
34.99	35.01	35.03	35.06	35.09	35.13	35.16	35.20	35.24	35.29
35.33	35.37	35.41	35.45	35.48	35.52	35.55	35.58	35.60	35.63
35.65	35.66	35.68	35.69	35.70	35.70	35.70	35.70	35.70	35.70
35.69	35.68	35.66	35.65	35.63	35.62	35.60	35.58	35.56	35.55
35.53	35.52	35.50	35.49	35.48	35.47	35.46	35.46	35.45	35.45
35.44	35.43	35.43	35.42	35.42	35.41	35.40	35.39	35.38	35.37
35.35	35.34	35.33	35.31	35.30	35.28	35.26	35.25	35.23	35.22
35.20	35.19	35.17	35.16	35.14	35.13	35.12	35.10	35.09	35.07
35.06	35.05	35.03	35.01	35.00	34.98	34.96	34.94	34.92	34.90
34.88	34.86	34.84	34.82	34.79	34.77	34.75	34.72	34.69	34.67
34.64	34.61	34.59	34.56	34.53	34.50	34.47	34.44	34.41	34.38
34.35	34.32	34.29	34.26	34.23	34.20	34.17	34.14	34.12	34.09
34.07	34.05	34.04	34.02	34.01	34.00	34.00	34.00	34.00	34.01
34.02	34.03	34.05	34.06	34.08	34.10	34.12	34.14	34.17	34.19
34.21	34.23	34.26	34.28	34.30	34.33	34.35	34.38	34.41	34.44
34.47	34.51	34.55	34.59	34.63	34.68	34.73	34.78	34.83	34.89
34.96	35.02	35.09	35.16	35.24	35.31	35.40	35.48	35.57	35.66
35.75	35.85	35.95	36.05	36.16	36.27	36.38	36.50	36.61	36.74
36.86	36.99	37.11	37.25	37.38	37.51	37.64	37.76	37.88	38.00
38.10	38.20	38.30	38.38	38.44	38.50	38.54	38.57	38.58	38.59

38.57	38.55	38.52	38.47	38.42	38.35	38.27	38.19	38.09	37.99
37.88	37.76	37.63	37.50	37.36	37.22	37.07	36.92	36.77	36.61
36.45	36.29	36.13	35.96	35.80	35.64	35.48	35.32	35.16	35.00
34.84	34.68	34.52	34.37	34.21	34.06	33.90	33.75	33.60	33.45
33.30	33.16	33.02	32.88	32.75	32.62	32.49	32.38	32.26	32.15
32.05	31.96	31.87	31.79	31.72	31.65	31.59	31.53	31.49	31.44
31.40	31.37	31.35	31.32	31.31	31.29	31.29	31.28	31.28	31.28
31.29	31.30	31.31	31.32	31.34	31.35	31.36	31.38	31.40	31.41
31.42	31.44	31.45	31.46	31.48	31.49	31.50	31.52	31.53	31.55
31.56	31.58	31.60	31.62	31.64	31.66	31.68	31.70	31.72	31.75
31.77	31.79	31.82	31.84	31.86	31.88	31.90	31.92	31.93	31.95
31.96	31.97	31.98	31.99	32.00	32.00	32.00	32.01	32.01	32.00
32.00	31.99	31.99	31.98	31.97	31.95	31.94	31.93	31.91	31.89
31.88	31.86	31.84	31.82	31.80	31.78	31.76	31.74	31.71	31.69
31.67	31.65	31.63	31.61	31.58	31.56	31.54	31.52	31.50	31.47
31.45	31.43	31.41	31.39	31.37	31.34	31.32	31.30	31.28	31.26
31.24	31.21	31.19	31.17	31.15	31.13	31.11	31.08	31.06	31.04
31.02	31.00	30.98	30.95	30.93	30.91	30.89	30.87	30.85	30.83
30.81	30.79	30.78	30.76	30.75	30.73	30.72	30.71	30.71	30.70
30.70	30.70	30.70	30.70	30.71	30.72	30.72	30.73	30.74	30.75
30.76	30.78	30.79	30.80	30.81	30.82	30.83	30.84	30.85	30.86
30.87	30.88	30.89	30.91	30.93	30.95	30.97	30.99	31.02	31.05
31.08	31.12	31.16	31.19	31.23	31.27	31.31	31.35	31.39	31.43
31.46	31.50	31.53	31.56	31.59	31.62	31.64	31.66	31.69	31.71
31.73	31.74	31.76	31.77	31.79	31.80	31.81	31.82	31.83	31.84
31.85	31.86	31.88	31.89	31.90	31.92	31.94	31.96	31.98	32.00
32.03	32.06	32.10	32.13	32.17	32.21	32.24	32.28	32.32	32.36
32.40	32.44	32.47	32.51	32.54	32.57	32.60	32.63	32.66	32.69
32.72	32.75	32.79	32.82	32.87	32.91	32.96	33.02	33.08	33.15
33.22	33.29	33.36	33.44	33.52	33.60	33.67	33.75	33.82	33.90
33.96	34.03	34.09	34.14	34.19	34.24	34.28	34.32	34.35	34.39
34.41	34.44	34.46	34.48	34.49	34.51	34.52	34.53	34.53	34.53
34.53	34.53	34.52	34.51	34.50	34.48	34.46	34.44	34.41	34.38
34.34	34.31	34.27	34.22	34.17	34.12	34.07	34.02	33.96	33.90
33.84	33.78	33.71	33.65	33.58	33.52	33.45	33.39	33.33	33.27
33.21	33.16	33.12	33.08	33.04	33.02	33.00	32.99	32.99	33.00
33.02	33.04	33.06	33.09	33.13	33.17	33.21	33.26	33.30	33.35
33.40	33.45	33.49	33.54	33.59	33.64	33.69	33.73	33.78	33.83
33.89	33.94	33.99	34.05	34.11	34.17	34.23	34.29	34.35	34.42
34.48	34.55	34.62	34.68	34.75	34.82	34.88	34.95	35.01	35.08
35.14	35.20	35.26	35.32	35.38	35.44	35.49	35.55	35.60	35.66
35.71	35.77	35.82	35.87	35.92	35.97	36.02	36.08	36.13	36.19
36.24	36.30	36.36	36.42	36.49	36.56	36.63	36.71	36.79	36.87
36.96	37.05	37.15	37.25	37.35	37.46	37.57	37.69	37.81	37.94
38.07	38.21	38.35	38.50	38.64	38.79	38.94	39.09	39.24	39.39
39.53	39.68	39.82	39.96	40.09	40.22	40.34	40.46	40.57	40.68
40.79	40.89	40.98	41.07	41.16	41.24	41.31	41.39	41.45	41.51
41.57	41.62	41.66	41.70	41.73	41.76	41.78	41.80	41.81	41.81
41.81	41.80	41.79	41.77	41.74	41.71	41.68	41.64	41.60	41.56
41.51	41.47	41.43	41.38	41.34	41.30	41.26	41.23	41.19	41.16
41.14	41.11	41.09	41.07	41.05	41.04	41.02	41.01	41.00	41.00
41.00	41.00	41.01	41.03	41.05	41.09	41.14	41.21	41.30	41.40
41.53	41.67	41.85	42.05	42.27	42.52	42.79	43.08	43.38	43.69
44.00	44.32	44.64	44.95	45.25	45.55	45.82	46.08	46.32	46.55
46.75	46.93	47.10	47.25	47.38	47.50	47.60	47.69	47.76	47.83
47.88	47.92	47.95	47.97	47.98	47.98	47.97	47.96	47.94	47.91
47.88	47.85	47.81	47.77	47.72	47.67	47.62	47.57	47.52	47.47
47.41	47.36	47.30	47.24	47.18	47.12	47.05	46.99	46.92	46.85
46.79	46.72	46.65	46.58	46.52	46.45	46.39	46.33	46.28	46.23
46.18	46.14	46.11	46.08	46.06	46.04	46.04	46.03	46.04	46.05
46.07	46.09	46.12	46.15	46.20	46.24	46.29	46.35	46.42	46.50
46.59	46.70	46.83	46.98	47.17	47.38	47.62	47.91	48.23	48.59
49.00	49.46	49.95	50.47	51.01	51.56	52.10	52.62	53.13	53.59

54.01	54.37	54.67	54.88	55.01	55.04	54.98	54.84	54.62	54.34
53.99	53.59	53.14	52.65	52.13	51.59	51.02	50.45	49.87	49.29
48.72	48.16	47.60	47.05	46.51	45.99	45.48	44.99	44.52	44.08
43.65	43.25	42.88	42.53	42.22	41.92	41.65	41.41	41.18	40.97
40.78	40.61	40.45	40.31	40.18	40.06	39.95	39.85	39.76	39.67
39.60	39.53	39.47	39.41	39.36	39.32	39.28	39.25	39.23	39.21
39.19	39.18	39.18	39.18	39.19	39.22	39.25	39.30	39.36	39.44
39.54	39.65	39.79	39.94	40.12	40.32	40.54	40.77	41.01	41.26
41.51	41.77	42.02	42.27	42.51	42.74	42.96	43.16	43.34	43.50
43.65	43.80	43.95	44.11	44.28	44.48	44.70	44.96	45.25	45.59
45.99	46.45	46.96	47.54	48.16	48.81	49.48	50.16	50.83	51.49
52.13	52.73	53.27	53.76	54.17	54.50	54.73	54.88	54.94	54.92
54.83	54.68	54.47	54.21	53.91	53.57	53.19	52.80	52.38	51.95
51.52	51.08	50.64	50.19	49.75	49.30	48.86	48.42	47.98	47.55
47.13	46.71	46.31	45.91	45.53	45.16	44.80	44.46	44.13	43.81
43.52	43.23	42.97	42.73	42.50	42.30	42.11	41.95	41.81	41.68
41.58	41.49	41.41	41.34	41.29	41.24	41.19	41.15	41.11	41.07
41.03	40.98	40.92	40.87	40.80	40.74	40.66	40.59	40.51	40.44
40.36	40.28	40.20	40.12	40.04	39.96	39.88	39.80	39.73	39.65
39.58	39.51	39.44	39.37	39.30	39.23	39.16	39.09	39.02	38.95
38.89	38.82	38.75	38.68	38.61	38.54	38.47	38.40	38.32	38.25
38.17	38.10	38.02	37.94	37.86	37.77	37.69	37.61	37.53	37.45
37.38	37.30	37.23	37.17	37.11	37.05	37.01	36.96	36.93	36.90
36.87	36.85	36.83	36.82	36.81	36.81	36.80	36.80	36.80	36.80
36.80	36.80	36.80	36.80	36.80	36.81	36.81	36.82	36.84	36.85
36.87	36.90	36.93	36.96	37.00	37.05	37.11	37.17	37.23	37.30
37.37	37.45	37.53	37.61	37.69	37.77	37.85	37.94	38.02	38.10
38.17	38.25	38.32	38.38	38.44	38.49	38.54	38.57	38.60	38.61
38.62	38.61	38.59	38.56	38.51	38.45	38.38	38.30	38.21	38.11
37.99	37.87	37.74	37.60	37.45	37.29	37.13	36.95	36.78	36.60
36.42	36.24	36.06	35.89	35.73	35.57	35.42	35.28	35.15	35.04
34.95	34.87	34.81	34.76	34.73	34.71	34.69	34.69	34.69	34.71
34.72	34.74	34.77	34.79	34.82	34.84	34.87	34.91	34.95	35.00
35.06	35.14	35.23	35.33	35.46	35.60	35.77	35.95	36.17	36.41
36.67	36.94	37.23	37.54	37.85	38.16	38.48	38.79	39.10	39.40
39.69	39.97	40.23	40.47	40.70	40.90	41.09	41.26	41.42	41.55
41.67	41.77	41.86	41.92	41.97	42.00	42.01	42.01	42.00	41.97
41.93	41.88	41.83	41.77	41.70	41.64	41.57	41.51	41.45	41.39
41.35	41.30	41.27	41.24	41.22	41.20	41.18	41.17	41.17	41.17
41.17	41.18	41.19	41.20	41.22	41.24	41.26	41.29	41.31	41.35
41.38	41.42	41.46	41.50	41.55	41.61	41.66	41.72	41.78	41.85
41.92	41.99	42.06	42.13	42.20	42.27	42.33	42.40	42.46	42.52
42.57	42.62	42.66	42.70	42.73	42.76	42.78	42.80	42.81	42.82
42.83	42.83	42.82	42.82	42.81	42.79	42.77	42.75	42.72	42.69
42.65	42.60	42.55	42.49	42.42	42.34	42.25	42.15	42.04	41.92
41.79	41.65	41.50	41.35	41.19	41.03	40.87	40.72	40.56	40.42
40.28	40.15	40.03	39.92	39.82	39.74	39.67	39.61	39.56	39.52
39.50	39.49	39.49	39.50	39.52	39.55	39.59	39.65	39.71	39.78
39.87	39.96	40.05	40.15	40.26	40.38	40.50	40.62	40.74	40.87
41.00	41.13	41.26	41.39	41.53	41.67	41.80	41.95	42.09	42.24
42.39	42.54	42.69	42.85	43.02	43.19	43.35	43.52	43.67	43.82
43.95	44.06	44.14	44.20	44.23	44.23	44.18	44.10	43.97	43.79
43.57	43.31	43.03	42.72	42.40	42.06	41.72	41.38	41.05	40.74
40.44	40.16	39.92	39.72	39.54	39.40	39.28	39.18	39.11	39.05
39.01	38.97	38.95	38.94	38.92	38.91	38.89	38.87	38.85	38.83
38.80	38.78	38.75	38.73	38.71	38.69	38.68	38.68	38.68	38.69
38.71	38.74	38.78	38.83	38.89	38.96	39.04	39.13	39.23	39.35
39.48	39.62	39.77	39.94	40.12	40.32	40.52	40.73	40.95	41.17
41.39	41.61	41.82	42.03	42.23	42.42	42.60	42.77	42.91	43.04
43.15	43.24	43.32	43.38	43.42	43.44	43.45	43.43	43.40	43.36
43.29	43.21	43.11	43.00	42.87	42.73	42.57	42.41	42.24	42.07
41.89	41.71	41.53	41.35	41.17	41.00	40.83	40.67	40.52	40.37
40.23	40.09	39.96	39.83	39.71	39.60	39.49	39.38	39.28	39.19

```
 39.10 39.02 38.94 38.86 38.79 38.72 38.66 38.60 38.54 38.48
 38.43 38.38 38.34 38.29 38.25 38.20 38.17 38.13 38.10 38.07
 38.04 38.02 38.01 37.99 37.99 37.99 37.99 38.00 38.02 38.05
 38.08 38.11 38.15 38.18 38.23 38.27 38.31 38.36 38.40 38.44
 38.48 38.52 38.55 38.58 38.61 38.63 38.65 38.67 38.68 38.69
 38.70 38.71 38.71 38.71 38.70 38.70 38.69 38.67 38.66 38.64
 38.62 38.60 38.58 38.55 38.53 38.50 38.47 38.44 38.41 38.38
 38.35 38.32 38.29 38.26 38.23 38.19 38.16 38.14 38.11 38.08
 38.05 38.03 38.01 37.98 37.96 37.94 37.93 37.91 37.90 37.89
 37.88 37.88 37.88 37.88 37.88 37.89 37.90 37.91 37.93 37.95
 37.98 38.01 38.04 38.08 38.12 38.17 38.22 38.28 38.34 38.41];


AntG=-AntdB';  Gr=AntG(:);     % dB

 if status == 1
  azint=-180:0.072:179.928;
  figure(1);
  plot(azint,Gr); grid;
  axis([-180 180 -60 0]);
  title('Search Radar Antenna Pattern');
  xlabel('Azimuth Angle (deg)'); ylabel('Relative Gain (dB)');

  figure(2);
  plot(azint,Gr); grid;
  axis([-10 10 -40 0]);
  title('Search Radar Antenna Main Lobe Pattern');
  xlabel('Azimuth Angle (deg)'); ylabel('Relative Gain (dB)');

  figure(3);
  subplot(2,1,2);
  for i=1:5000
      GS(i)=10^(Gr(i)/10);
  end;
  plot(azint,GS,'o'); grid;

  axis([-5.5 5.5 0 1]);
  xlabel('Azimuth Angle (deg)'); ylabel('Normalized Gain');

 end;  % (if)

end;
```

```
function [Gr]=ant_gel(status);
%
% ant_gel
%
%  status=0, transfer the antenna gain
%         1, plot the antenna pattern
%
%  AN/SPS-49  Reflector Antenna Gain Pattern
%
%  Elevation: -20 ~ 44, digitized per degree, unit -dB
%

AntdB=[30.0 30.0 30.0 30.0 30.0 30.0 30.0 27.5 22.0 19.0
       15.5 13.0 11.0  8.5  7.0  5.5  4.0  3.0  2.0  1.4
        0.8  0.4  0.1  0.0  0.1  0.4  0.9  1.7  2.3  3.3
        4.8  5.8  6.9  7.5  8.2  8.4  8.8  9.3 10.0 10.4
       11.0 11.9 12.5 13.0 13.5 14.0 14.6 15.2 16.0 17.2
       19.1 20.7 22.0 23.0 23.8 24.6 26.0 27.1 28.7 30.0];

AntG=-AntdB';  Gr=AntG(:);     % dB

 if status == 1
  azint=-20:1:44;
  figure(1);
  plot(azint,Gr); grid;
  axis([-20 45 -30 0]);
  title('Search Radar Antenna Pattern');
  xlabel('Elevation (deg)'); ylabel('Relative Gain (dB)');

end;
```

```
% env_22
%
% RADAR ECHO SIMULATION
%                     -- Simulation
%                              -- Echo Verification
%                                       -- Amp. (Zero Threshold)
%
%  plot amplitude cell map   (Zero Threshold)
%

   sec_s=p_pa(1);
   sec_e=p_pa(2);
   rng_s=p_pa(3)*1.852e3;        %  m <--- NM
   rng_e=p_pa(4)*1.852e3;        %  m <--- NM
   amp_s=p_pa(5);
   amp_e=p_pa(6);

    Rmin_c=round(rng_s/dR);
    Rmax_c=round(rng_e/dR);
    if Rmin_c < 1
       Rmin_c=1;
    end
    if Rmax_c > M
       Rmax_c=M;
    end
    Rmin=Rmin_c*dR/1.852e3; Rmax=Rmax_c*dR/1.852e3;
    Raxis=Rmin:dR/1.852e3:Rmax;                 % range (NM)

    Bmin_c=round(sec_s/Dtheta);
    Bmax_c=round(sec_e/Dtheta);
    if Bmin_c < 1
       Bmin_c=1;
    end
    if Bmax_c > N
       Bmax_c=N;
    end
    Bmin=Bmin_c*Dtheta; Bmax=Bmax_c*Dtheta;
    Baxis=Bmin:Dtheta:Bmax;                     % sector (deg)


    fig_echo3D1=figure('NumberTitle','off',...
               'Name','Radar Echo - Amplitude (Zero Threshold)',....
               'MenuBar','none','Position',[550 60 450 415]);

    mesh(Baxis,Raxis,Amp(Bmin_c:Bmax_c,Rmin_c:Rmax_c)');

    grid; axis([Bmin Bmax Rmin Rmax amp_s amp_e]);
    title('Radar Echo Amplitude Cell-Map');
    ylabel('Range (NM)'); xlabel('Azimuth (deg)'); zlabel('Amplitude');
    view(45,20);

    fig_echo2D=figure('NumberTitle','off',...
               'Name','Radar Echo - Amplitude (Zero Threshold)',....
               'MenuBar','none','Position',[20 60 500 415]);

    mesh(Baxis,Raxis,Amp(Bmin_c:Bmax_c,Rmin_c:Rmax_c)');

    grid; axis([Bmin Bmax Rmin Rmax 0 10*log10(amp_e)]);
    title('Radar Echo Amplitude Cell-Map');
    ylabel('Range (NM)'); xlabel('Azimuth (deg)');
    view(0,90);

end;
```

```
% env_23
%
% RADAR ECHO SIMULATION
%                        -- Simulation
%                                 -- Echo Verification
%                                          -- Amp. (Fixed Threshold)
%
%  plot amplitude cell map   (Fixed Threshold)
%


   sec_s=p_pa(1);
   sec_e=p_pa(2);
   rng_s=p_pa(3)*1.852e3;        %  m <--- NM
   rng_e=p_pa(4)*1.852e3;        %  m <--- NM
   amp_s=p_pa(5);
   amp_e=p_pa(6);

    Rmin_c=round(rng_s/dR);
    Rmax_c=round(rng_e/dR);
    if Rmin_c < 1
       Rmin_c=1;
    end
    if Rmax_c > M
       Rmax_c=M;
    end
    Rmin=Rmin_c*dR/1.852e3; Rmax=Rmax_c*dR/1.852e3;
    Raxis=Rmin:dR/1.852e3:Rmax;              % range (NM)

    Bmin_c=round(sec_s/Dtheta);
    Bmax_c=round(sec_e/Dtheta);
    if Bmin_c < 1
       Bmin_c=1;
    end
    if Bmax_c > N
       Bmax_c=N;
    end
    Bmin=Bmin_c*Dtheta; Bmax=Bmax_c*Dtheta;
    Baxis=Bmin:Dtheta:Bmax;                  % sector (deg)

    AmpT=Amp;

    for i=Bmin_c:Bmax_c
      for j=Rmin_c:Rmax_c
          if Amp(i,j) < VT_fixed
             AmpT(i,j)=VT_fixed;
          end
      end
    end


    fig_echo3D=figure('NumberTitle','off',...
               'Name','Radar Echo - Amplitude (Fixed Threshold)',....
               'MenuBar','none','Position',[550 60 450 415]);

    sn_3d=mesh(Baxis,Raxis,AmpT(Bmin_c:Bmax_c,Rmin_c:Rmax_c)');

    grid; axis([Bmin Bmax Rmin Rmax amp_s amp_e]);
    title('Radar Echo Amplitude Cell-Map');
    ylabel('Range (NM)'); xlabel('Azimuth (deg)');
    zlabel('Amplitude (A/D count)');
    view(45,20);
```

```
    fig_echo2D=figure('NumberTitle','off',...
               'Name','Radar Echo - Amplitude (Fixed Threshold)',....
               'MenuBar','none','Position',[20 60 500 415]);

    mesh(Baxis,Raxis,AmpT(Bmin_c:Bmax_c,Rmin_c:Rmax_c)');

    grid; axis([Bmin Bmax Rmin Rmax 0 10*log10(amp_e)]);
    title('Radar Echo Amplitude Cell-Map');
    ylabel('Range (NM)'); xlabel('Azimuth (deg)');
    view(0,90);

end
```

```
% env_24
%
% RADAR ECHO SIMULATION
%                         -- Simulation
%                                  -- Echo Verification
%                                           -- Doppler Frequency
%
%  plot Doppler Frequency cell map
%


   sec_s=p_pa(1);
   sec_e=p_pa(2);
   rng_s=p_pa(3)*1.852e3;          %  m <--- NM
   rng_e=p_pa(4)*1.852e3;          %  m <--- NM

   K=ceil(dAZ/Dtheta);             %  PDI period

    Rmin_c=round(rng_s/dR);
    Rmax_c=round(rng_e/dR);
    if Rmin_c < 1
       Rmin_c=1;
    end
    if Rmax_c > M
       Rmax_c=M;
    end
    Rmin=Rmin_c*dR/1.852e3; Rmax=Rmax_c*dR/1.852e3;
    Raxis=Rmin:dR/1.852e3:Rmax;                  % range (NM)

    Bmin_c=round(sec_s/Dtheta);
    Bmax_c=round(sec_e/Dtheta);
    if Bmin_c < 1
       Bmin_c=1;
    end
    if Bmax_c > N
       Bmax_c=N;
    end

    BK=round((Bmax_c-FFTn-Bmin_c)/K);            % PDI frames
    Baxis=1:BK;

    Dfd=prf/FFTn;                                % Doppler resolution
    Fmin=0;
    Fmax=Dfd*(FFTn-1);                           % 0 - prf
    Faxis=Fmin:Dfd:Fmax;                         % Doppler frequency (Hz)

    det_Dpf=zeros(BK,Rmax_c);
    det_amp=zeros(BK,Rmax_c);
    power=zeros(FFTn,Rmax_c);

 for i=1:BK

   P_idx=(i-1)*K+1;
   P_idx1=P_idx+FFTn-1;

   for j=Rmin_c:Rmax_c

       amp=SIQ(P_idx:P_idx1,j);
       ZY=fft(SIQ(P_idx:P_idx1,j),FFTn);
       power(:,j)=abs(ZY);
       [w,idx]=max(power(:,j));
       det_Dpf(i,j)=idx;                        % find the max filter output
       [ampmax,P_idx2]=max(abs(amp));
```

```
        det_amp(i,j)=(ampmax);                    % find the max pulse amplitude

     end;  % (j)

  end;  % (i)


  %  sort frequency and amplitude by range order

  fd_map=zeros(FFTn,Rmax_c);

  for j=Rmin_c:Rmax_c
    for i=1:BK
        x=det_Dpf(i,j);
        if fd_map(x,j) < det_amp(i,j)
           fd_map(x,j)=det_amp(i,j);
        end
    end
  end

  fdmax=max(max(fd_map));

     fig_echo3D=figure('NumberTitle','off',...
                'Name','Radar Echo - Doppler Frequency',....
                'MenuBar','none','Position',[550 60 450 415]);

     sn_3d=mesh(Faxis,Raxis,fd_map(1:FFTn,Rmin_c:Rmax_c)');

     grid; axis([Fmin Fmax Rmin Rmax 0 fdmax]);
     title('Radar Echo Doppler Frequency Spectrum');
     ylabel('Range (NM)'); xlabel('Frequency (Hz)'); zlabel('Amplitude');
     view(45,20);


end;
```

```
% simula
%
% RADAR PROCESSING SIMULATION Worksheet
%
% File          sim_11 | Open...   |
%
% Simulation    sim_21 | Radar Processing      |
%               sim_22 | Control & Display     |
%               sim_23 | Amp/Phase Extraction |
%

%-----------  create pop-up menu ----------------------------------------

fig_sim=figure('NumberTitle','off','Name','RADAR PROCESSING SIMULATION',...
               'MenuBar','none','Resize','off','Position',[55 300 600 350]);

sim_op1=uimenu(gcf,'Label','File');
        uimenu(sim_op1,'Label','Open...',             'CallBack','sim_11');

sim_op2=uimenu(gcf,'Label','Simulation');
        uimenu(sim_op2,'Label','Radar Processing',    'CallBack','sim_21');
        uimenu(sim_op2,'Label','Control & Display',   'CallBack','sim_22');
        uimenu(sim_op2,'Label','Amp/Phase Extraction','CallBack','sim_23');

end;
```

```
% sim_11
%
%  RADAR PROCESSING SIMULATION
%                                -- File
%                                        -- Open...
%
%

%------------  create file open window ---------------------------------------

pa_file='';
fig_open=figure('NumberTitle','off','Name','Open','Color',[1 1 1],...
                'MenuBar','none','Position',[280 320 350 180]);

 uicontrol(gcf,'Style','text','String','Radar Echo',...
               'BackG',[1 1 1],'ForeG',[0 0.75 0],'Position',[45 100 100 30]);
 uicontrol(gcf,'Style','text','String','File Name:',...
                'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[45 75 100 30]);
 uicontrol(gcf,'Style','text','String','',...
                'BackG',[0 0 0],'Position',[50 50 100 36]);
 uicontrol(gcf,'Style','text','String','',...
                'BackG',[1 1 1],'Position',[51 51  98 34]);
 ed_pa_file=uicontrol(gcf,'Style','edit','String',pa_file,...
                'BackG',[1 1 1],'ForeG',[0 0 0],'Position',[56 51 90 26],...
                'Callback',['pa_file=get(ed_pa_file,''String'');']);

%------------  create file selection pushbutton ---------------------------

uicontrol(gcf,'Style','pushbutton','Position',[200 100  80  30],...
              'String','OK',...
              'CallBack',['delete(fig_open)',';','sim_111']);

uicontrol(gcf,'Style','pushbutton','Position',[200 50  80  30],...
              'String','Cancel','CallBack','delete(fig_open);');

end;
```

```
% sim_111
%
%  RADAR PROCESSING SIMULATION
%                                   -- File
%                                           -- Open file
%
%
%
%  open simulated radar echo file
%
%  display radar echo coverage and simulation worksheet


%  set text color for  field name

black  =[0    0    0   ]; white   =[1 1    1   ];
red    =[0.75 0    0   ]; green   =[0 0.75 0   ];
yellow =[0.75 0.75 0   ]; lt_blue =[0 0.75 0.75];
gray   =[0.75 0.75 0.75]; blue    =[0 0    0.75];
dk_gray=[0.6  0.6  0.6 ]; dk_green=[0 0.25 0   ];


%  set text field size

tw=170;             % width for item name
th=23;              % heigh for item name (parameter)
td=25;              % vertical distance between two item (parameter) td > th
aw=50;              % width for parameter

%------- file handle (radar echo file) -------------------------------

eval(['load d:\matlab\bin\chen\thesis\',pa_file,';']);

% load 'pa_file e_pa'
% load 'env_sec env_rg SIQ pw prf FFTn VT_fixed dAZ
%       PC_no RB_no Ru Scan_rate RRE_coef'
%

item_file='Radar Echo File:';

tx=50; ty=300;     % initial position for 1st item name (left,top)

uicontrol(gcf,'Style','text','String',item_file,...
              'BackG',blue,'ForeG',white,'Position',[tx ty 150 td]);
uicontrol(gcf,'Style','text','String',pa_file,...
              'BackG',blue,'ForeG',white,'Position',[tx+150 ty 75 td]);

%  set strings item_name

e_titl='Radar Echo Coverage';
e_pn(1,:)='Scan Sector     (deg)';
e_pn(2,:)='Detection Range  (NM)';
e_pa(1)=env_sec;
e_pa(2)=env_rg;

%  establish text sheet

tx=50; ty=230;     % initial position for 1st item name (left,top)

  uicontrol(gcf,'Style','text','String',e_titl,...
                'BackG',green,'ForeG',white,'Position',[tx ty+td tw+aw+2 th]);
  for i=1:2
    uicontrol(gcf,'Style','text','String',e_pn(i,:),...
```

```
                'BackG',gray, 'Position',[tx ty-(i-1)*td tw th]);

    uicontrol(gcf,'Style','text','String',num2str(e_pa(i)),...
         'BackG',blue,'ForeG',white','Position',[tx+tw+2 ty-(i-1)*td aw th]);
  end;

%------------  create Make selection pushbutton ----------------------------

cp_x=230; cp_y=100; cp_w=180; cp_d=35;

uicontrol(gcf,'Style','push','String','Radar Processing',...
                      'Position',[cp_x-1 cp_y+40 cp_w cp_d],...
                      'CallBack','sim_21');



end;
```

```
% sim_21
%
%  RADAR PROCESSING SIMULATION
%                                  -- Simulation
%                                          -- Radar Processing
%
%  radar digital signal processing
%
%    [Doppler Filter   ]  Doppler Bin cell-map
%    [Envelope Detector]  Amplitude cell-map
%
%
%

global Dpf_amp; global det_amp;
global prf; global Scan_rate; global VT_fixed; global DRB_no;


%  display the radar processing status

cp_x=230; cp_y=95; cp_w=178;

mk_bar2=uicontrol(gcf,'Style','text','BackG',red,...
                  'String','',...
                  'Position',[cp_x   cp_y   0.1    20]);

mk_bar1=uicontrol(gcf,'Style','text','BackG',white,...
                  'Position',[cp_x   cp_y   cp_w   20]);

mk_bar0=uicontrol(gcf,'Style','text','BackG',gray,...
                  'Position',[cp_x-2 cp_y-2 cp_w+4 24]);


Dtheta=Scan_rate/prf;

M=RB_no;
N=PC_no;

det_amp=zeros(N,M);
det_Dpf=zeros(N,M);
Dpf_amp=zeros(N,FFTn);
power=zeros(FFTn,M);

 %-------- Envelope Detector ----------------------------

 Amp=round(abs(SIQ));

 %--------- Doppler Filter ------------------------------

 Dtheta=Scan_rate/prf;                     % pulse increment angle
 K=ceil(dAZ/Dtheta);                       % PDI period
 NK=round((N-FFTn-1)/K);                   % PDI frames
 Dfd=prf/FFTn;                             % Doppler resolution


mk_pn=0;       % reset processing status = 0%

 for i=1:NK

  mk_pn=i/NK;
  set(mk_bar2,'Position',[cp_x cp_y cp_w*mk_pn 20]);

   P_idx=(i-1)*K+1;
```

```
   P_idx1=P_idx+FFTn-1;

   for j=1:M
       ZY=fft(SIQ(P_idx:P_idx1,j),FFTn);
       power(:,j)=abs(ZY);
       [w,fidx]=max(power(:,j));
       [ampmax,aidx]=max(Amp(P_idx:P_idx1,j));
       pix=P_idx+aidx-1;
       if det_amp(pix,j) < ampmax
         det_Dpf(pix,j)=fidx;                % keep the max filter output
         det_amp(pix,j)=ampmax;              % keep the max pulse amplitude
         if Dpf_amp(pix,fidx) < ampmax
            Dpf_amp(pix,fidx)=ampmax;        % amplitude for Doppler bin
         end
       end
     end

    end;  % (j)

 end;  % (i)


delete(mk_bar2); delete(mk_bar1); delete(mk_bar0);


%------  create simulation function pushbutton -------------------------

uicontrol(gcf,'Style','text','Position',[  46 25 530 40],'BackG',white);
uicontrol(gcf,'Style','text','Position',[  48 27 526 36],'BackG',black);
uicontrol(gcf,'Style','text','Position',[ 230 50 150 25],...
              'String','Simulation','BackG',black,'ForeG',white);


uicontrol(gcf,'Style','pushbutton','Position',[52 30  155 25],...
              'String','Control & Display',   'CallBack','sim_22');

uicontrol(gcf,'Style','pushbutton','Position',[212 30 175 25],...
              'String','Amp/Phase Extraction','CallBack','sim_23');

uicontrol(gcf,'Style','pushbutton','Position',[392 30 175 25],...
              'String','        -----        ','CallBack','');



end
```

```
% sim_22
%
%  RADAR PROCESSING SIMULATION
%                          -- Simulation
%                                   -- Control & Display
%
%
%

global disp_dr;
global hndl_tl; global hndl_sl; global hndl_clk;
global hndl_fs; global hndl_ps; global Zpix;


deg2rad=pi/180;  rad2deg=180/pi;


fig_ppi=figure('NumberTitle','off','Name','Radar Processing Simulation',...
               'Color',dk_gray,'Position',[50 50 550 550],...
               'Resize','off','MenuBar','none');

figure(fig_ppi);
hold on;

%
%   Create PPI Display
%
RB_no=round(RB_no);
Rmax=env_rg*1.852e3;          % m <-- NM
Rmark=Rmax/5;                 % range marker resolution (m)
dR=Rmax/RB_no;
DRB_no=RB_no;

az_mark=1;                    % azimuth marker resolution (deg)

disp_rad=150;                 % display circle radius (pixels)
disp_dr=disp_rad/Rmax;        % pixels/m;


Rg=disp_rad; cx=0; cy=0;
plot(cx,cy,'.','Color',black,'MarkerSize',680);    % inner scope
ang0=0:pi/180:2*pi;
px=cx+Rg*cos(ang0); py=cy+Rg*sin(ang0);
plot(px,py,'Color',dk_green,'LineWidth',10);       % outer ring

L1=[disp_rad disp_rad+5];
ang1=pi/180*az_mark:pi/180*az_mark:2*pi;           % azimuth marker
rx=cx+L1'*cos(ang1); ry=cy+L1'*sin(ang1);
plot(rx,ry,'Color',green,'LineWidth',1);

L1=[disp_rad-4 disp_rad+5];                        % azimuth marker
ang1=pi/180*15:pi/180*15:2*pi;                     % every 15 deg
rx=cx+L1'*cos(ang1); ry=cy+L1'*sin(ang1);
plot(rx,ry,'Color',green,'LineWidth',2);

rx=[-(disp_rad-4) disp_rad-4]; ry=[cy cy];         % x-y axes dash line marker
plot(rx,ry,'Color',green,'LineWidth',1,'LineStyle',':');
rx=[cx cx]; ry=[disp_rad-4 -(disp_rad-4)];
plot(rx,ry,'Color',green,'LineWidth',1,'LineStyle',':');

text(-5,170,'0','FontSize',10,'Color',white);      % azimuth marker
text(165,0,'90','FontSize',10,'Color',white);      % 0,90,180,270 deg
text(-12,-170,'180','FontSize',10,'Color',white);
text(-188,0,'270','FontSize',10,'Color',white);
```

```
ang0=0:pi/180:2*pi;                                    % range marker
mk_dr=disp_dr*Rmark;
mk_no=Rmax/Rmark-1;
L0=[mk_dr:mk_dr:mk_no*mk_dr];
px=cx+cos(ang0)'*L0; py=cy+sin(ang0)'*L0;
plot(px,py,'Color',green,'LineWidth',1);

lx=disp_rad+15;  ly=disp_rad+15;
axis([-lx lx -ly ly]);
axis('equal');
axis('off');



%
% initialize the MainBeam scan line (Timer Control)
%
Rg=[0,146];
lx=cx-cos(90*deg2rad)*Rg;
ly=cy+sin(90*deg2rad)*Rg;
hndl_sl=plot(lx,ly,'Color',[0 1 0],'EraseMode','Xor','LineWidth',1);

%
% initialize the target (dot) (Timer Control)
%

Xpix=zeros(1,145); Ypix=zeros(1,145); Zpix=zeros(1,145);

 for i=1:145
  hndl_tl(i)=plot(Xpix(i),Ypix(i),'.','Color',[0 0 0],'EraseMode','none',...
                                                    'MarkerSize',1);
 end


%
%-------------  clock timer display  -----------------------------------
%
         uicontrol(gcf,'Style','text',...
              'BackG',black,'ForeG',black,'Position',[ 29 519 142 22]);
         uicontrol(gcf,'Style','text','String','Timer (sec):',...
              'BackG',white,'ForeG',black,'Position',[ 30 520 100 20]);
hndl_clk=uicontrol(gcf,'Style','text','String','0.0',...
              'BackG',white,'ForeG',black,'Position',[130 520  40 20]);

%
%-------------  display max range setting  -----------------------------
%
         uicontrol(gcf,'Style','text',...
              'BackG',black,'ForeG',black,'Position',[329 519 142 22]);
         uicontrol(gcf,'Style','text','String','Range (NM):',...
              'BackG',white,'ForeG',black,'Position',[330 520 100 20]);
set_Rmax=uicontrol(gcf,'Style','edit','String',num2str(Rmax/1.852e3),...
              'BackG',white,'ForeG',black,'Position',[430 520  40 20],...
 'Callback',['Rmax=str2num(get(set_Rmax,''String''))*1e3;',...
             'Rmark=Rmax/5;','disp_dr=disp_rad/Rmax;','DRB_no=Rmax/dR;']);

%------------  display control pushbutton ----------------------------

uicontrol(gcf,'Style','text','Position',[ 140 15 300 35],'BackG',white);
uicontrol(gcf,'Style','text','Position',[ 142 17 296 31],'BackG',black);

uicontrol(gcf,'Style','pushbutton','Position',[300 20 130 25],...
```

```
               'String','Clear Trails','CallBack','sim_2213');

%
% Initialize the Power and Doppler Frequency Spectrum (Time Control)
%
fig_spa=figure('NumberTitle','off','Name','Amp/Phase Extraction',...
               'MenuBar','none','Position',[614 55 393 306]);
%              ,'Color',dk_green_color,'Resize','off');

M=DRB_no;
ps_x=1:M;       ps_y=zeros(1,M);

pf_x=1:FFTn; F=length(pf_x); pf_y=zeros(1,F);

subplot(2,1,1);
hndl_ps=plot(ps_x,ps_y,'Color',[1 1 0],'EraseMode','Xor','LineWidth',1);
grid; axis([1 M 0 max(max(det_amp))]);
 ylabel('Amplitude'); xlabel('Range Bin');

subplot(2,1,2);
hndl_fs=plot(pf_x,pf_y,'Color',[1 1 0],'EraseMode','Xor','LineWidth',1);
grid; axis([1 FFTn 0 max(max(det_amp))]);
 ylabel('Amplitude'); xlabel('Doppler Bin');


%
%  call simulink
%

sim_221;

end;
```

```
function [ps]=sim_2211(t)
%
% sim_2211
%
% PPI display for echo amplitude > Threshold
%
% called by simulink sim_221.m
%

global disp_dr;
global hndl_tl; global hndl_sl;  global hndl_clk;
global det_amp; global VT_fixed; global Scan_rate; global prf; global DRB_no;


deg2rad=pi/180;

% timer update

    set(hndl_clk,'String',num2str(t));

% main beam update

    DRu=[0,146];
    lx=-cos((t*Scan_rate+90.72)*deg2rad)*DRu;
    ly=sin((t*Scan_rate+90.72)*deg2rad)*DRu;
    set(hndl_sl,'Xdata',lx,'Ydata',ly);
    drawnow;

% scanned line echo update

ps=145/DRB_no;            %   ppi scale:  145 pixel ~ Range Bin


ti=t*prf+1;           %   azimuth scan line
Zpix=zeros(145,3);
Zpix(30,:)=[0 0.75 0]; Zpix(60,:)=[0 0.75 0];
Zpix(90,:)=[0 0.75 0]; Zpix(120,:)=[0 0.75 0];
set(hndl_tl(30),'Markersize',1);
set(hndl_tl(60),'Markersize',1);
set(hndl_tl(90),'Markersize',1);
set(hndl_tl(120),'Markersize',1);

Rpix=1:145;
Xpix=-cos((t*Scan_rate+90)*deg2rad)*Rpix;
Ypix=sin((t*Scan_rate+90)*deg2rad)*Rpix;


  for i=1:DRB_no
     if det_amp(ti,i) > VT_fixed
        j=ceil(i*ps);
        Zpix(j,:)=[1 1 1];
        set(hndl_tl(j),'Markersize',10);
     end

  end


  for i=1:145
      set(hndl_tl(i),'Xdata',Xpix(i),'Ydata',Ypix(i),'Color',Zpix(i,:));
      drawnow;
  end

end;
```

```
function [i]=sim_2212(t)
%
% sim_2212
%
% animation plot for Amplitude/Doppler freq. Spectrum at time base
%
% called by simulink sim_221.m
%

%-----------------------------------------------------------------

global hndl_ps; global hndl_fs;
global Dpf_amp; global det_amp; global prf;


    i=t*prf+1;
    sp_amp=det_amp(i,:);
    sp_Dpf=Dpf_amp(i,:);

    set(hndl_ps,'Ydata',sp_amp);
    set(hndl_fs,'Ydata',sp_Dpf);

    drawnow;
end
```

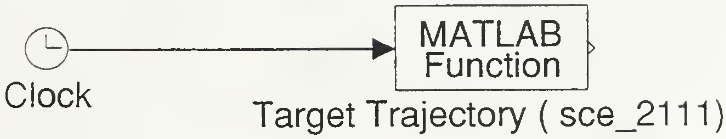
```
% sim_2213
%
% Radar Processing Simulation
%                         ---  Simulation
%                               --- Control & Display
%
%  [ Clear Trail ]  PPI display control
%


figure(fig_ppi);
hold on;

%
%   Create PPI Display
%

Rg=disp_rad; cx=0; cy=0;
plot(cx,cy,'.','Color',black,'MarkerSize',680);    % inner scope

rx=[-(disp_rad-4) disp_rad-4]; ry=[cy cy];         % x-y axes dash line marker
plot(rx,ry,'Color',green,'LineWidth',1,'LineStyle',':');
rx=[cx cx]; ry=[disp_rad-4 -(disp_rad-4)];
plot(rx,ry,'Color',green,'LineWidth',1,'LineStyle',':');

ang0=0:pi/180:2*pi;                                % range marker
mk_dr=disp_dr*Rmark;
mk_no=Rmax/Rmark-1;
L0=[mk_dr:mk_dr:mk_no*mk_dr];
px=cx+cos(ang0)'*L0; py=cy+sin(ang0)'*L0;
plot(px,py,'Color',green,'LineWidth',1);

%
% initialize the MainBeam scan line (Timer Control)
%
Rg=[0,146];
lx=cx-cos(90*deg2rad)*Rg;
ly=cy+sin(90*deg2rad)*Rg;
hndl_sl=plot(lx,ly,'Color',[0 1 0],'EraseMode','Xor','LineWidth',1);

%
% initialize the target (dot) (Timer Control)
%

Xpix=zeros(1,145); Ypix=zeros(1,145); Zpix=zeros(1,145);

 for i=1:145
  hndl_tl(i)=plot(Xpix(i),Ypix(i),'.','Color',[0 0 0],'EraseMode','none',...
                                                     'MarkerSize',1);
 end


end;
```

```
% sim_23
%
%  RADAR PROCESSING SIMULATION
%                                 -- Simulation
%                                         -- Amp/Phase Extraction
%
%  radar digital signal pre-processing
%
%    [Doppler Filter    ]  Doppler Bin cell-map
%    [Envelope Detector]  Amplitude cell-map
%
%
%

%----------- plot cell-map -------------------------------------------

    Baxis=1:N;
    Raxis=1:M;
    Faxis=1:FFTn;

    fig_echo3D1=figure('NumberTitle','off',...
               'Name','Amplitude Extraction',....
               'MenuBar','none','Position',[300 90 550 415]);

    mesh(Baxis,Raxis,det_amp');

    grid; axis([1 N 1 M 0 max(max(det_amp))]);
    title('Amplitude Cell-Map');
    ylabel('Range Bin'); xlabel('Pulse'); zlabel('Amplitude');
    view(45,20);

    fig_echo3D2=figure('NumberTitle','off',...
               'Name','Doppler Frequency Extraction',....
               'MenuBar','none','Position',[500 30 550 415]);

    mesh(Baxis,Faxis,Dpf_amp');

    grid; axis([1 N 1 FFTn 0 max(max(Dpf_amp))]);
    title('Doppler Frequency Cell-Map');
    ylabel('Doppler Bin'); xlabel('Pulse'); zlabel('Amplitude');
    view(45,20);

end;
```

APPENDIX C. SIMULINK MODELS

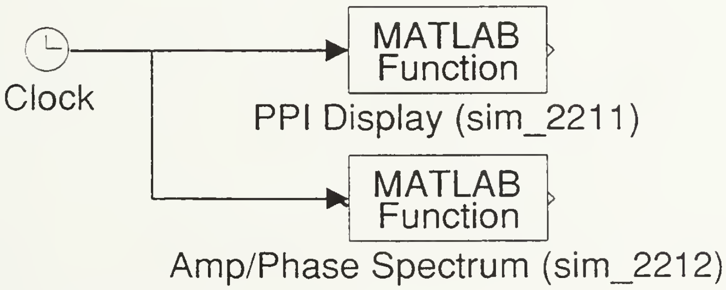
1. Target Trajectory

Simulink model -- `sce_211.m`



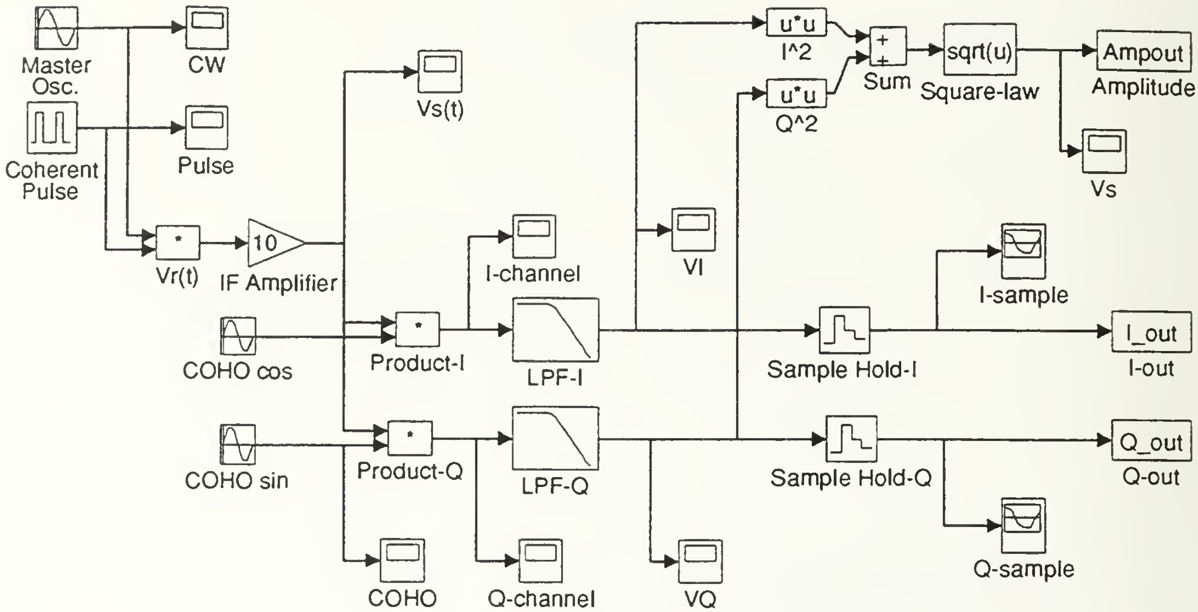
2. Control and Display

Simulink model -- `sim_221.m`



3. Synchronous Detector

Simulink model -- `mod_251.m`



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